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RECOMMENDED LOI PROCEDURES FOR HYBRID LUNAR MISSIONS

Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
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PROJECT APOLLO

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By Charles E. Foggatt, Dallas G. Ives,
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1.0 SUMMARY

Modifications to the current LOI abort philosophy are recommended in this document to remove deficiencies in abort capability caused by use of non-free-return translunar trajectories in nominal mission planning. The complete LM backup to SPS failures during LOI that exists for free-return lunar missions does not necessarily exist for hybrid missions.

The current abort procedure results in a region of LOI burn time when the LM is unable to return the CSM to earth if an SPS failure occurs. A recommended abort technique is presented which removes this gap in abort capability. The technique involves use of an onboard crew chart and possible use of the APS engine in the docked configuration.

2.0 INTRODUCTION

If an SPS failure occurs during the LOI burn, the LM would be required to provide the necessary return-to-earth ΔV. For a lunar mission based on a free-return translunar trajectory, a DPS abort capability exists throughout the LOI burn (ref. 1 and 2). The effect on LOI abort capability for non-free-return lunar missions is discussed in reference 3. Briefly, a region may occur during the LOI burn when the DPS cannot provide the necessary abort ΔV.

This document serves two major purposes: (1) It shows the LOI abort capability that exists with the current LOI abort technique for various hybrid lunar missions. The specific launch dates considered are those days in the Apollo 11 launch window when a hybrid trajectory was planned. (2) The improvement in abort capability when the recommended abort procedures are used in illustrated. A complete description of current and proposed abort philosophy is included in the following paragraphs.

3.0 SYMBOLS

APS	ascent propulsion subsystem
CSM	command and service modules
CM	command module
DPS	descent propulsion subsystem
DSKY	display keyboard
DVM	LOI ΔV magnitude
FCUA	fuel-critical unspecified area
g.e.t.	ground elapsed time
IMU	inertial measurement unit
LM	lunar module
LOI	lunar orbit insertion
MSFN	Manned Space Flight Network
n.a.	not applicable
PGNCS	primary guidance and navigation control system
RCS	reaction control subsystem
RTCC	Real-Time Computer Complex
SM	service module
SPS	service propulsion subsystem
t_D	delay time from LOI ignition to abort
ΔV	delta velocity
ΔV_1	ΔV of mode II corrective maneuver

4.0 CURRENT LOI ABORT PHILOSOPHY

4.1 Characteristics of Trajectories that Result From Premature LOI Shutdown

The discussion in references 1 and 2 of the classes of trajectories after an SPS failure during LOI applies here. The actual burn times for each class of trajectory is a function of the launch date, but they are approximately as follows.

a. Hyperbola: LOI-1 ignition to LOI-1 ignition plus 2 minutes

b. Unstable ellipse: LOI-1 ignition plus 2 minutes to LOI-1 ignition plus 3 minutes

c. Stable ellipse: LOI-1 ignition plus 3 minutes to LOI-2 shutdown

One important difference that should be noted here is that the initial hyperbola of class a (LOI-1 burn time = 0 sec) is no longer a free-return trajectory but requires a substantial ΔV to return to earth.

4.2 General Abort Modes

Lunar phase abort manuevers are of three basic types.

a. Mode I - a one-impulse maneuver that returns the spacecraft directly to earth. The burn is initiated as soon as possible after LOI termination to reduce the necessary ΔV. The applicable preabort trajectory class is the hyperbolic region (fig. 1).

b. Mode II - a two-impulse maneuver that necessitates one intermediate lunar orbit. The first impulse is directed down the radius vector and is initiated as soon as possible after LOI termination. The burn reduces the orbital period and provides a stable intermediate orbit. The second burn occurs near perilune and injects the spacecraft on the transearth trajectory (fig. 2).

c. Mode III - a one-impulse maneuver initiated near perilune after one or more orbits (similar to the normal TEI burn). This mode is used when class c (stable ellipse) trajectories occur. By definition, the preabort period is less than 15 hours (fig. 3).

4.3 Current LOI Abort Ground Rules

In reference 3, there is an extensive discussion of the abort capability which exists for premature SPS shutdowns during LOI for hybrid missions. The primary difference between free-return and hybrid missions is a gap region in the hybrid LOI burn during which the LM lacks the capability to return the CSM to earth.

The current LOI abort ground rules are as follows.

a. Manual SPS shutdowns

1. LOI ignition to beginning of gap: initiate mode I 15-minute SPS abort by use of an onboard crew chart (ref.3, section 4.7).

2. No manual shutdowns should be attempted during gap or remainder of LOI burn.

b. Inadvertent SPS shutdowns

1. LOI ignition to middle of gap: initiate mode I 15-minute SPS abort by use of an onboard crew chart.

2. Middle of gap to end of LOI-1: attempt immediate SPS restart and complete LOI.

c. After a total SPS failure

1. LOI ignition to beginning of gap: initiate DPS mode I abort at LOI_{IG} plus 2 hours.

2. End of gap to stable lunar ellipse (preabort period = 15 hr): initiate DPS mode II abort with first burn at LOI_{IG} plus 2 hours.

3. Remainder of LOI burn: initiate DPS mode III abort after one revolution.

Note that the ground rules do not provide an abort procedure for the total LOI burn after a total SPS failure. That is, the current hybrid mission abort procedures, which evolved from earlier free-return lunar mission planning, do not provide a total return-to-earth capability.

4.4 Summary of Current LOI Abort Capability for Various Hybrid Lunar Missions

As illustrated in reference 3, the DPS abort capability varies significantly for different hybrid mission profiles. For example, the duration of the LOI burn when the DPS lacks the capability to return the CSM to earth after an SPS failure is shown in the following table. (Examples are Apollo 11 hybrid launch dates.)

Launch date	LOI burn duration, sec	Gap duration, sec
July 18, 1969	352.3	-6 (overlap)
July 21, 1969	337.2	55
August 14, 1969	341.6	30
August 16, 1969	337.6	53
August 20, 1969	376.6	81
September 13, 1969	359.6	9
September 15, 1969	366.8	15
September 18, 1969	365.4	98

The abort ΔV requirements throughout the LOI burn for the above cases are shown in figures 4(a) through 4(g). (Data for September 13, 1969, are not included here because they were shown in ref. 3.) The mode I aborts and mode II first burns are initiated at 2 hours past LOI ignition.

For reference, additional data are included for the mode II aborts in figures 5 and 6. The ΔV magnitude of the first DPS burn for the respective launch dates of figures 4(a) through 4(g) are shown in figures 5(a) through 5(g). The time between DPS burns and the perilune altitude of the intermediate ellipse (after the first DPS burn) are shown in figures 6(a) through 6(g).

The primary constraint on the current abort capability is the 2-hour minimum initiation time of the DPS abort. This number was arrived at through Apollo Abort Working Group meetings, Data Priority Contingency Techniques meetings, and other working group discussions. The 2-hour delay allows time for LM activation, MSFN tracking, and RTCC abort PAD generation. Although the abort ΔV could be reduced if the delay time was reduced (which would extend the mode I region), the current value was sufficient for the free-return lunar missions under consideration. However, with the inception of hybrid mission planning, the 2-hour delay time is a severe restriction.

5.0 RECOMMENDED LOI ABORT PHILOSOPHY

5.1 Recommended Abort Modes

The abort modes presented in section 4.2 again apply here with only slight modifications. However, it is recommended that the mode I DPS maneuver nominally be initiated at LOI_{IG} plus 30 minutes for a region of the LOI burn. Because this time is insufficient for normal MSFN tracking and RTCC abort solution generation, this maneuver will be targeted by use of an onboard crew chart. This chart would be used in a maneuver similar to the mode I 15-minute SPS chart which is included in the current abort techniques and is discussed in reference 3, section 4.7.

Rather than the normal mode I PGNCS external ΔV burn, the crew chart DPS burn would be initiated in a manual mode which is currently being discussed in Data Priority Techniques meetings. The burn would be in a fixed inertial attitude that would be determined by the crew chart.

Basically, the 30-minute DPS abort procedure is as follows.

a. After SPS shutdown, the crew maneuvers the CSM/LM combination to a set of gimbal angles relative to the CM IMU orientation. The gimbal angles are included in the chart and the same regardless of LOI burn duration.

2. The abort ΔV magnitude is read from the chart and is a function of the LOI DVM read from the DSKY after shutdown. The burn time is indicated on the chart as a backup.

3. The DPS burn is initiated at LOI_{IG} plus 30 minutes. Therefore, a constant time of ignition results. The DPS burn is accomplished in a manual mode that results in a fixed inertial attitude.

In addition to the mode I 30-minute DPS abort, the recommended abort modes include use of the APS engine in the docked CSM/LM configuration. Although the APS engine cannot be gimballed to achieve attitude control, a procedure is currently being developed that will permit use of the APS engine in an abort situation. The procedure involves rotation of the CSM/LM interface to reduce masalinement errors, and use of the LM/RCS translation thrusters to control attitude deviations during the APS burn.

Complete descriptions of the manual DPS and APS burn procedures are beyond the scope of this document, but it is noted that work is underway to verify their feasibility and develop detailed crew procedures.

Use of the APS engine could apply to both the mode I and Mode II situations. If a mode I abort is required and the 30-minute chart cannot result in a satisfactory transearth coast because of DPS ΔV limitations, the APS can provide the additional ΔV (mode Ia). Likewise, a mode II abort could consist of two DPS burns similar to the current abort procedure, with the addition of an APS burn (mode IIa). As will be seen in subsequent sections, however, the mode IIa abort is required only for a limited number of extreme hybrid missions.

Finally, because the applicability of the mode I 15-minute SPS abort (originally designed during free-return mission planning) has been greatly reduced because a hybrid mission is used, it is recommended that it no longer be included in the LOI abort philosophy.

5.2 Recommended LOI Abort Ground Rules

The recommended LOI abort ground rules are as follows.

a. Manual SPS shutdowns: no manual shutdowns are recommended during the LOI burn for trajectory reasons.

b. Inadvertent SPS shutdowns: attempt immediate SPS restart and complete LOI.

c. After a nonrestartable SPS shutdown

1. LOI ignition to [a]40 seconds: initiate a mode I DPS abort at 2 hours past LOI ignition. Although the burn is planned at LOI_{IG} plus 2 hours, a delay to 5 hours is possible (RTCC).

2. [a]40 seconds to [a]97 seconds: initiate a mode I DPS abort at 30 minutes past LOI ignition by use of an onboard crew chart.

3. [a]97 seconds to [a]130 seconds: initiate a mode I DPS abort at 30 minutes past LOI ignition by use of an onboart crew chart. Jettison the descent stage and initiate an APS burn (mode Ia) at LOI_{IG} plus 90 minutes (RTCC).

4. [a]130 seconds to [a]156 seconds: initiate the normal mode II DPS abort.

5. [a]156 seconds to end of LOI-1: initiate the normal mode III DPS abort.

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[a]Numbers are shown for a typical hybrid lunar mission but are a function of the launch date (section 5.3).

To reiterate the discussion of section 5.1, a mode II abort with both the DPS and APS engines may be required in a limited number of hybrid missions. This abort is illustrated in the following section.

5.3 Comparison of Abort Capability for Current and Recommended Abort Procedures

It was noted in a previous section that the 2 hour minimum abort time for the mode I DPS abort was the primary constraint on LOI abort capability. The effect caused by reduction of this delay time is presented in this section.

The abort ΔV required for mode I and mode II aborts for a typical hybrid lunar mission (July 21, 1969 launch date) is shown in figure 7. Mode I aborts simulated by an impulsive abort burn are shown for delay times past LOI ignition of 0.5 hour, 1.0 hour, 1.5 hours, and 2.0 hours. The dashed line shows the actual ΔV requirements for a 30-minute mode I crew chart (finite burn simulation). Although the mode II abort requirements improve slightly as the first burn delay time is reduced, a modification to the current procedure is not warranted.

The following table summarizes the improvement in abort capability as the mode I delay time is reduced.

ABORT CAPABILITY FOR A TYPICAL HYBRID MISSION (JULY 21, 1969 LAUNCH)		
Mode I ignition	Gap duration	Burn
LOI_{IG} plus 0.5 hr	11	Impulsive
LOI_{IG} plus 1.0 hr	47	Impulsive
LOI_{IG} plus 1.5 hr	57	Impulsive
LOI_{IG} plus 2.0 hr	61	Impulsive
30-minute chart	21	finite (crew chart)

The 30-minute crew chart ΔV is higher than the 30-minute impulsive data because the finite burn is initiated at 30 minutes and is equivalent to an impulsive burn ignited at a later delay time. This effect is not significant for aborts at LOI_{IG} plus 2 hours.

In an effort to compare the abort capability for the current and recommended abort procedures, four typical hybrid missions were selected, and data are shown in figures 8(a) and 8(d). Mode I data are shown for the normal 2-hours DPS abort as well as a 30-minute crew chart. Mode II data are shown for the normal abort procedure.

Three ΔV available lines are shown: DPS only, DPS and APS, and DPS plus 500 fps. The DPS plus 500 fps line is included for the following reason. The crew chart ΔV required line is extended past the DPS only ΔV available line. In this region, the ΔV would apply to a DPS burn immediately followed by an APS burn. Because a finite delay time between the DPS and APS burns is required to rotate the docking interface as well as to provide an RTCC abort solution, the actual ΔV would increase as the burn is delayed. Analysis has indicated that a 500-fps APS ΔV would increase by 100 fps if the burn were delayed 1 hour past DPS ignition. Because the APS ΔV available is approximately 700 fps, a reserve of 100 fps would be left.

In figures 8(a) through 8(d), a bar graph is shown for both the current and proposed abort procedures to indicate the applicable region of LOI burn time for each of the abort modes. In all cases, the gap in abort capability which exists for the current abort procedures is no longer a problem.

The applicable regions of LOI burn time are summarized in the following table for each of the proposed abort modes.

APPLICABLE LOI BURN REGION FOR ABORT MODES

Date	Mode I(2 hr), sec	Mode I(30 min), sec	Mode Ia sec
7-21-69	0 to 40	40 to 130	97 to 130
8-14-69	0 to 54	54 to 150	117 to 150
9-15-69	0 to 90	90 to 180	158 to 180
9-18-69	0 to 31	31 to 122	81 to 122

Date	Mode IIa, sec	Mode II, sec	Mode III, sec
7-21-69	n.a.	110 to 156	156 to end
8-14-69	n.a.	103 to 160	160 to end
9-15-69	n.a.	121 to 180	180 to end
9-18-69	114 to 156	156 to 176	176 to end

The point in the LOI burn that the mode I 2-hour abort was ended was chosen as the point at which the abort could not be delayed greater that 5 hours past LOI ignition before the ΔV requirements exceeded the DPS ΔV available. In addition, the 30-minute crew chart is not extended into the LOI burn earlier than this point primarily because the return inclination of the resultant transearth coast is unacceptable for shutdowns early in the burn if the crew chart is used.

Finally, the use of the recommended abort procedures not only improves abort capability but also eliminates the longer period mode II intermediate ellipses in many cases. The following table shows the largest mode II intermediate period for both the current and recommended abort techniques.

MAXIMUM PERIOD OF MODE II INTERMEDIATE ELLIPSES		
Launch date	Current procedures, hr	Proposed procedures, hr
July 21, 1969	22.8	18.9
August 14, 1969	26.0	16.2
September 15, 1969	31.6	15.0
September 18, 1969	18.6	26.0

The maximum period of the intermediate ellipse increases for the September 18, 1969 hybrid when the proposed procedures are used because the mode IIa abort is required to fill the gap between mode Ia and Mode II.

Note that the September 15, 1969 hybrid no longer requires the mode II abort. This situation is representative of the one that will exist when the proposed abort procedures are applied to free-return lunar missions.

6.0 CONCLUSIONS

Modifications to the current LOI abort procedures are presented which will remove the present limitations in hybrid mission abort capability. The procedures are basically similar to those for free-return lunar missions with the exception that the use of the APS engine in the docked configuration is included.

In the proposed abort procedures, the normal delay time of 2 hours after LOI ignition for a DPS abort burn has been removed with the introduction of a 30-minute DPS crew chart. Use of this chart is similar to use of the current mode I 15-minute SPS crew chart which is no longer required in the proposed abort techniques.

The procedures required for use of the APS engine in the docked configuration as well as the DPS engine in a manual mode (crew chart targeted burn) are currently being defined. Consequently, the abort capability which will exist when those recommended abort procedures are implemented is presented for several typical hybrid lunar missions.

LOI MODE I ABORT

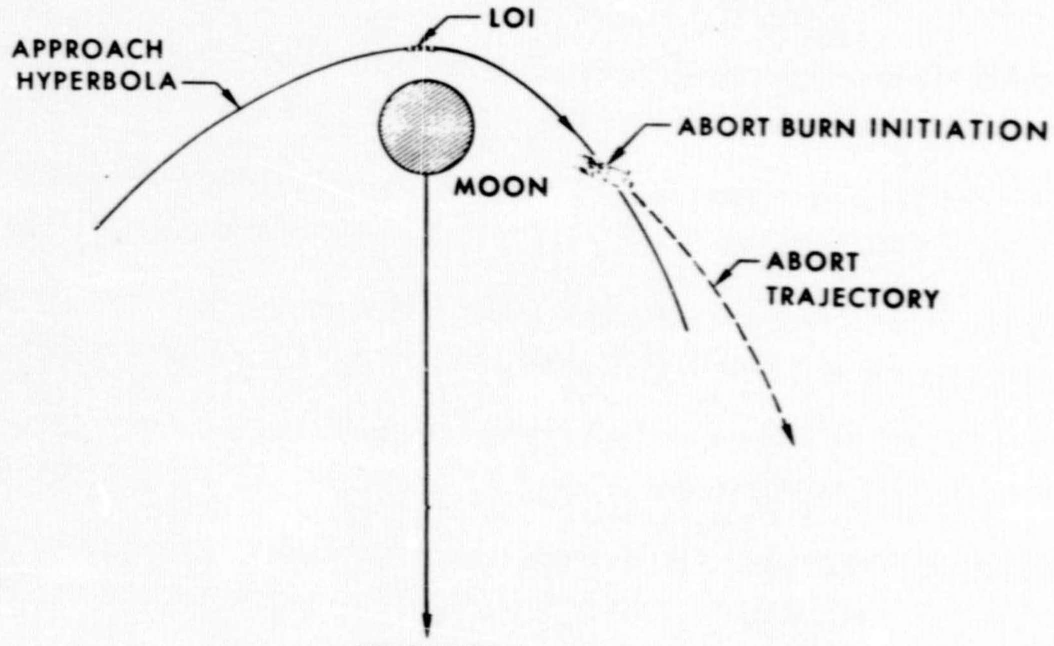


Figure 1.- Mode I abort geometry following an SPS failure during LOI.

LOI MODE II ABORT

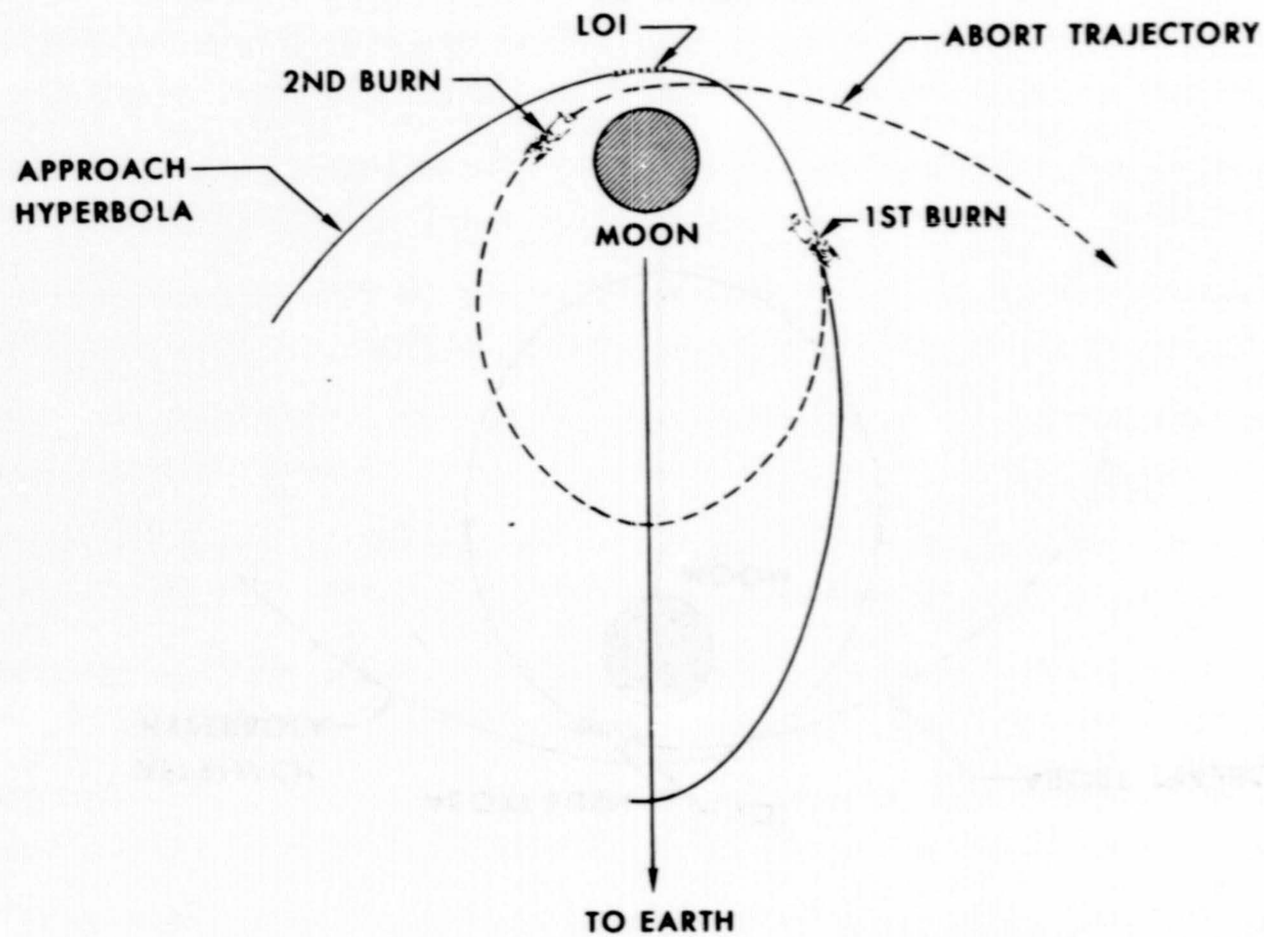


Figure 2.- Mode II abort geometry following an SPS failure during LOI.

LOI MODE III ABORT

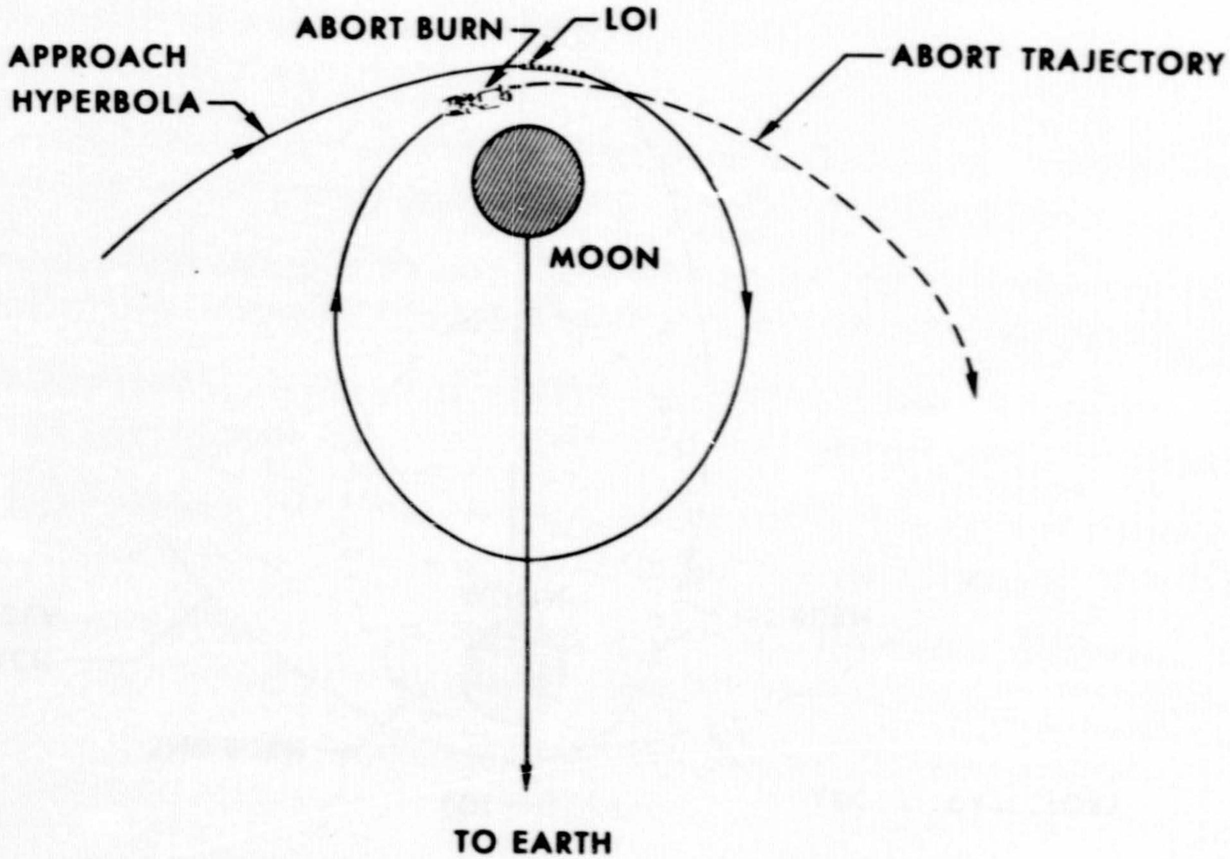
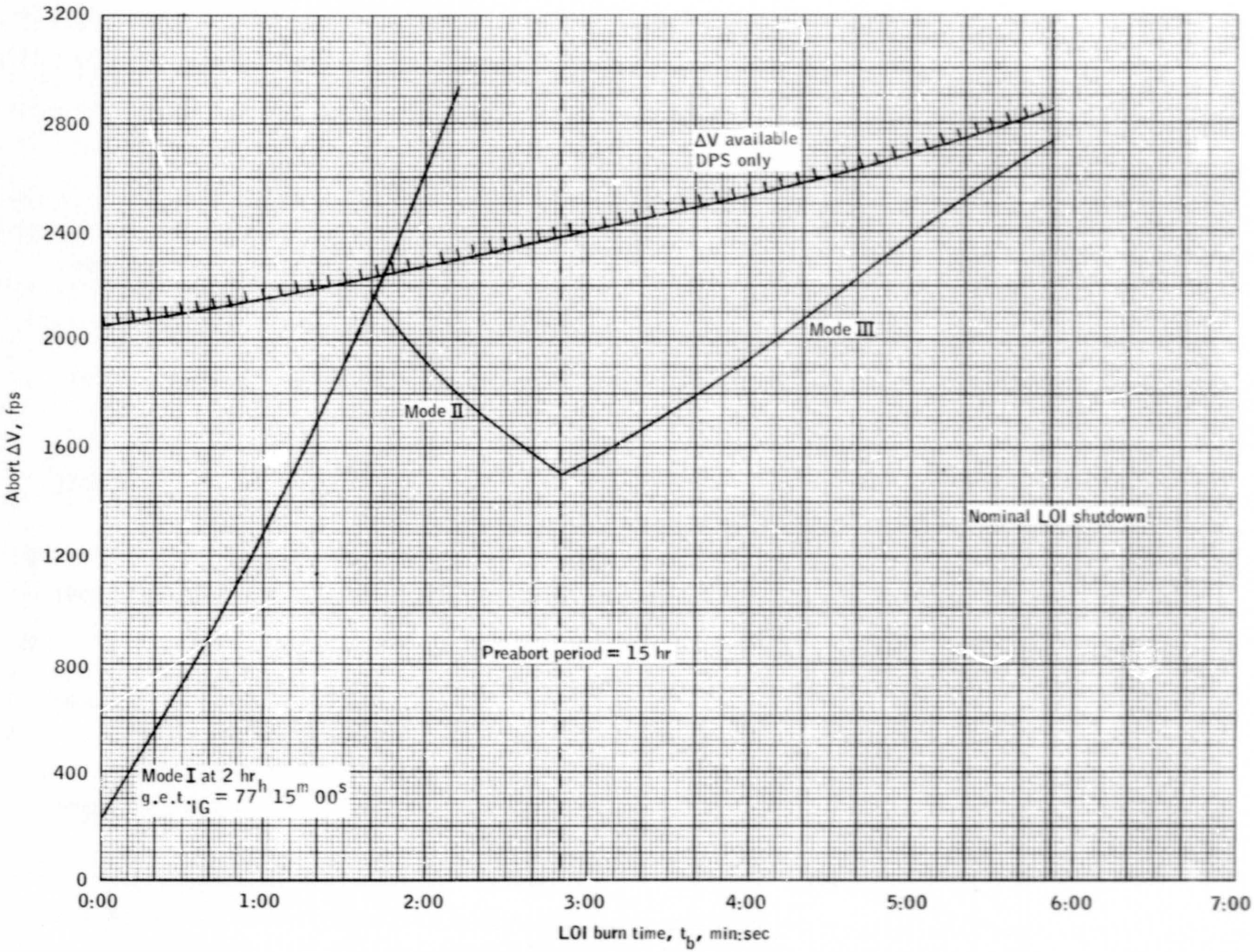
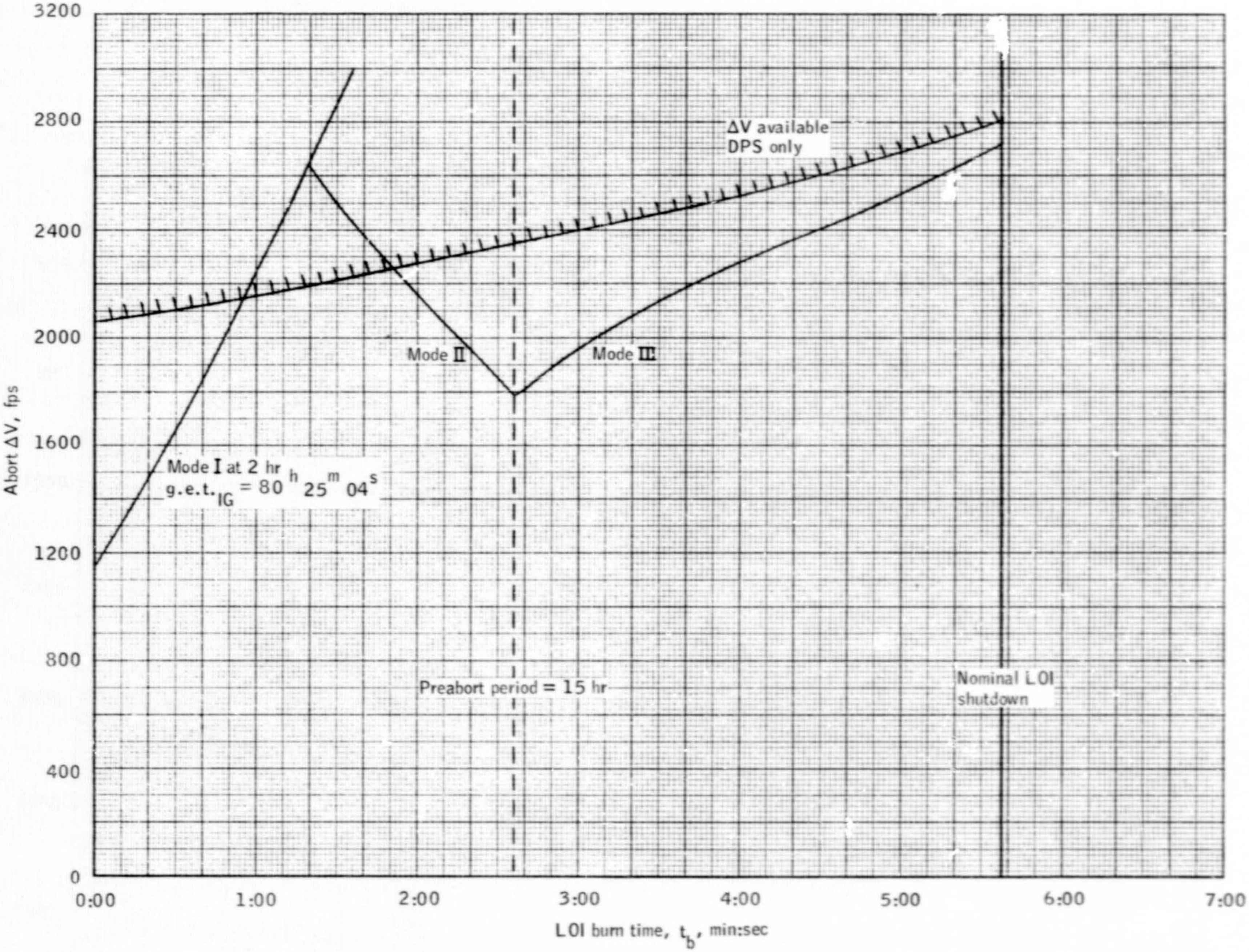


Figure 3.- Mode III abort geometry following an SPS failure during LOI.



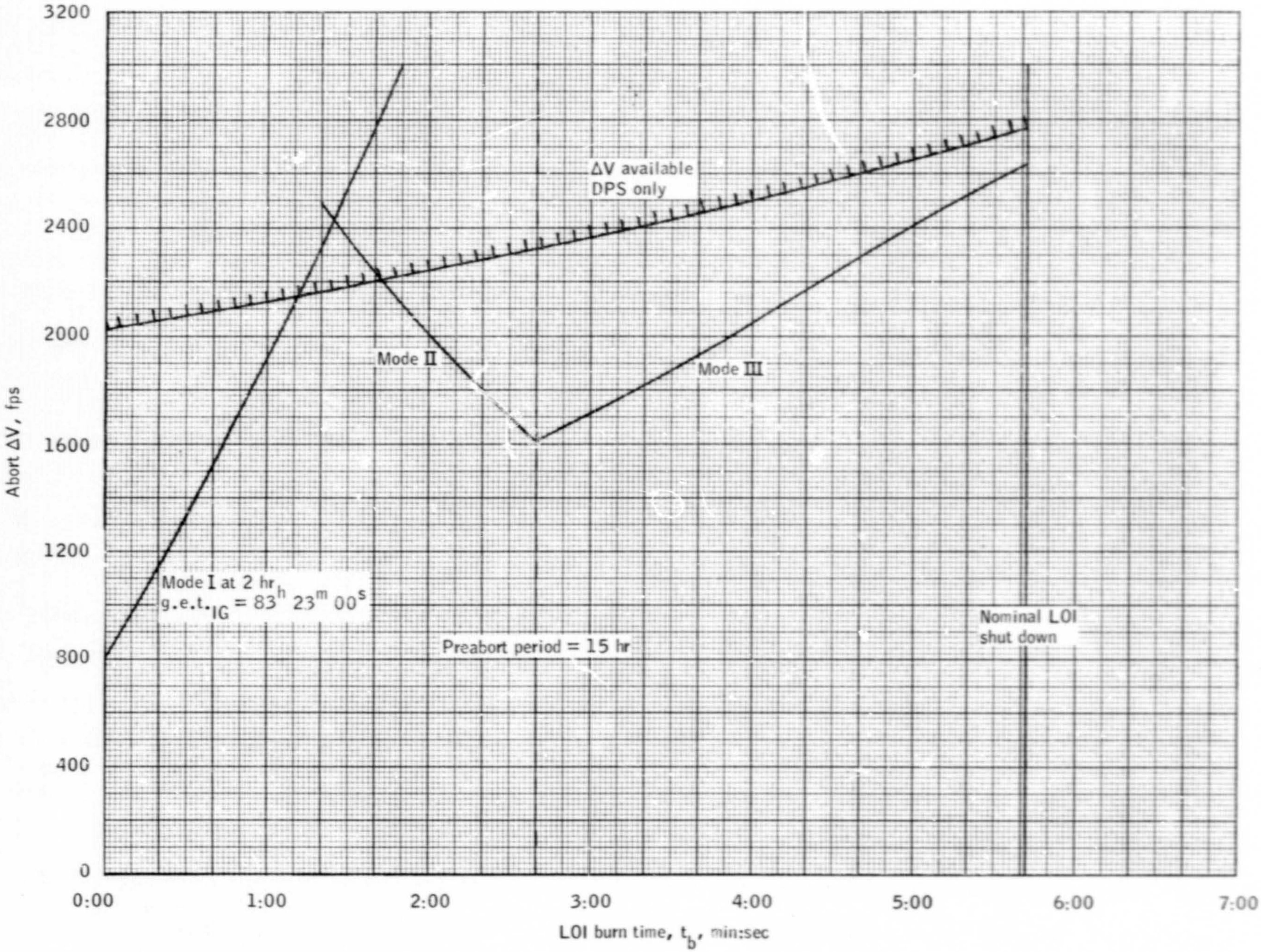
(a) July 18, 1969; 89.3° launch azimuth; first opportunity.

Figure 4.- Summary of current LOI abort capability for various hybrid lunar missions (FCUA returns).



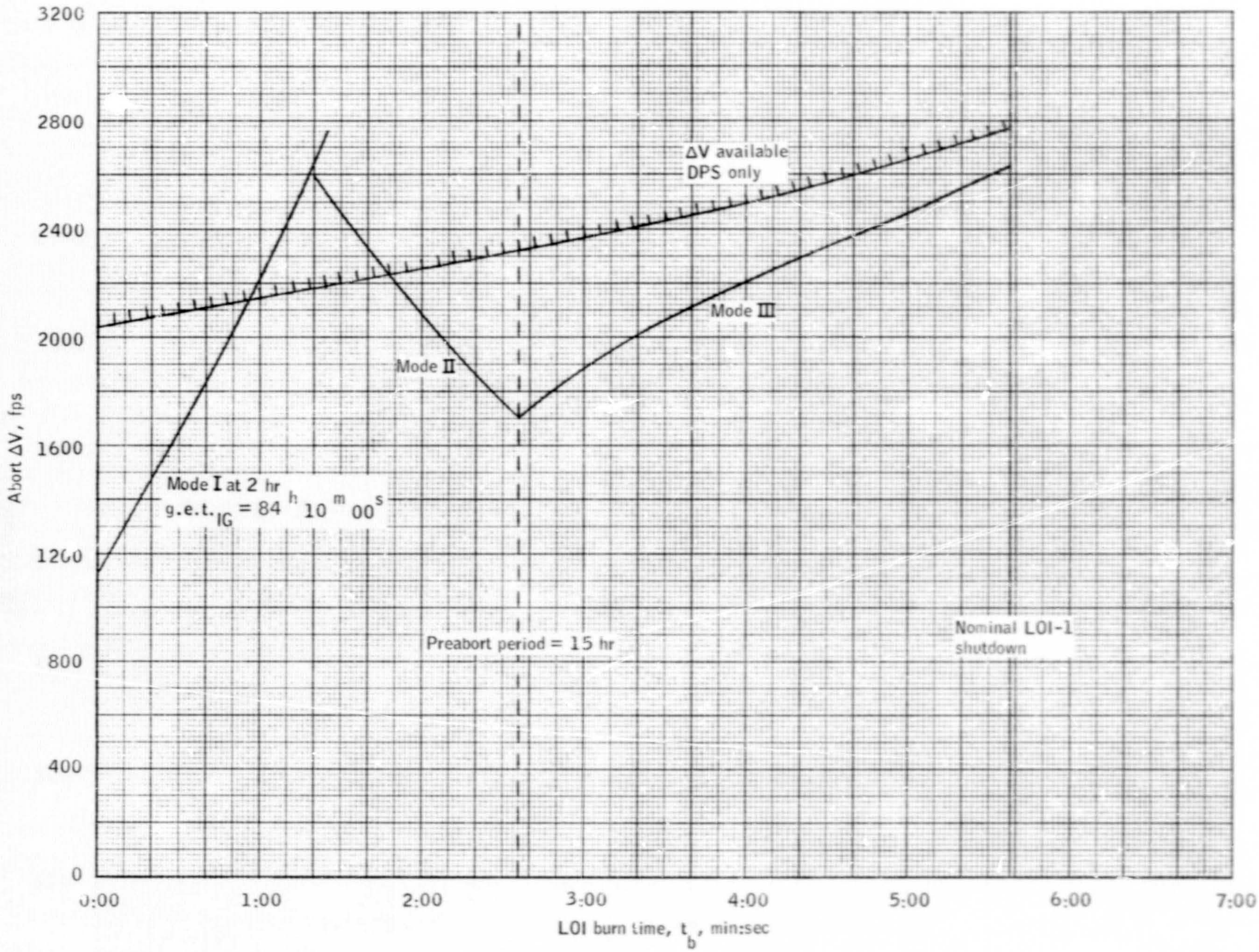
(b) July 21, 1969; 74.7° launch azimuth; first opportunity.

Figure 4.- Continued.



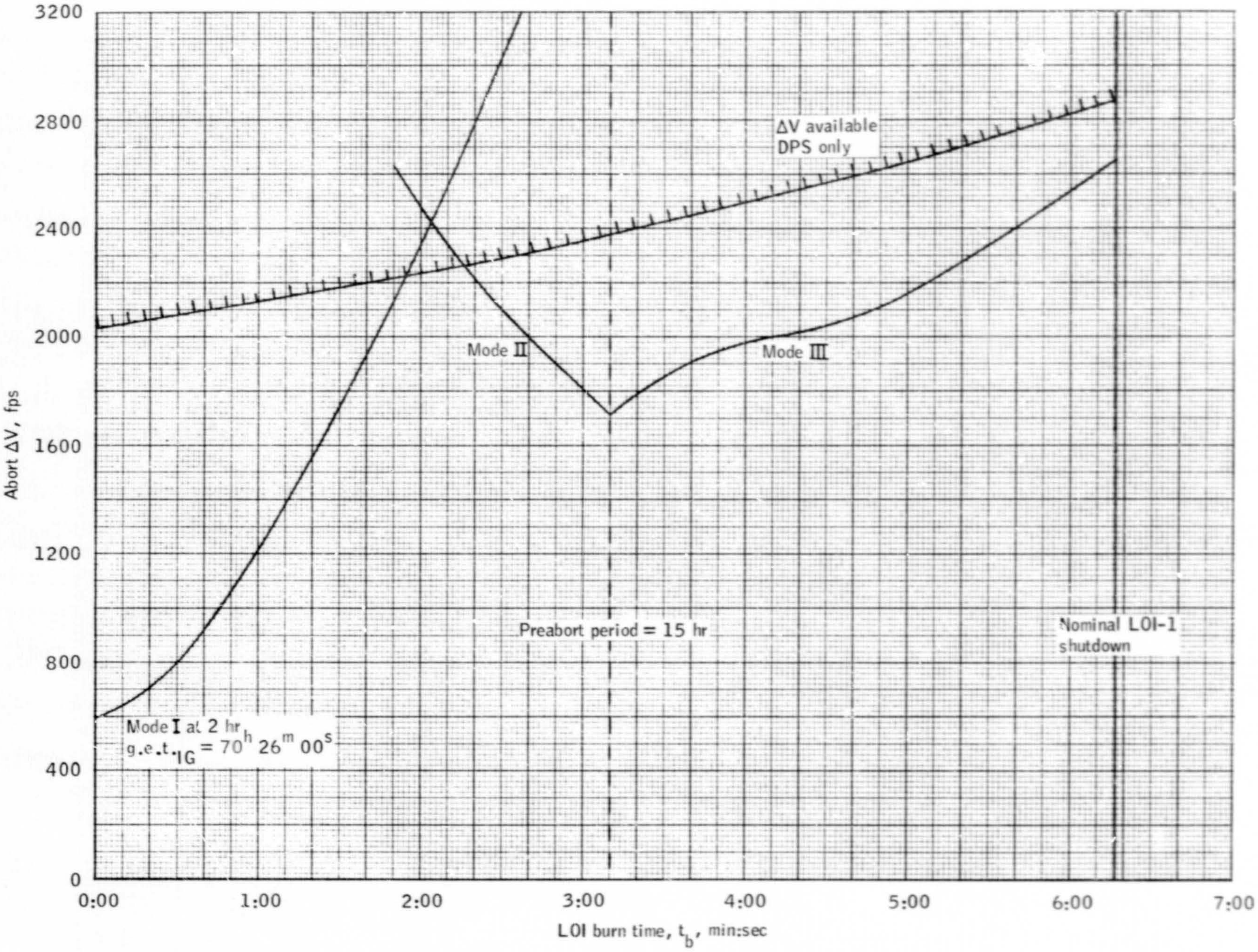
(c) August 14, 1969; 72° launch azimuth; first opportunity.

Figure 4.- Continued.



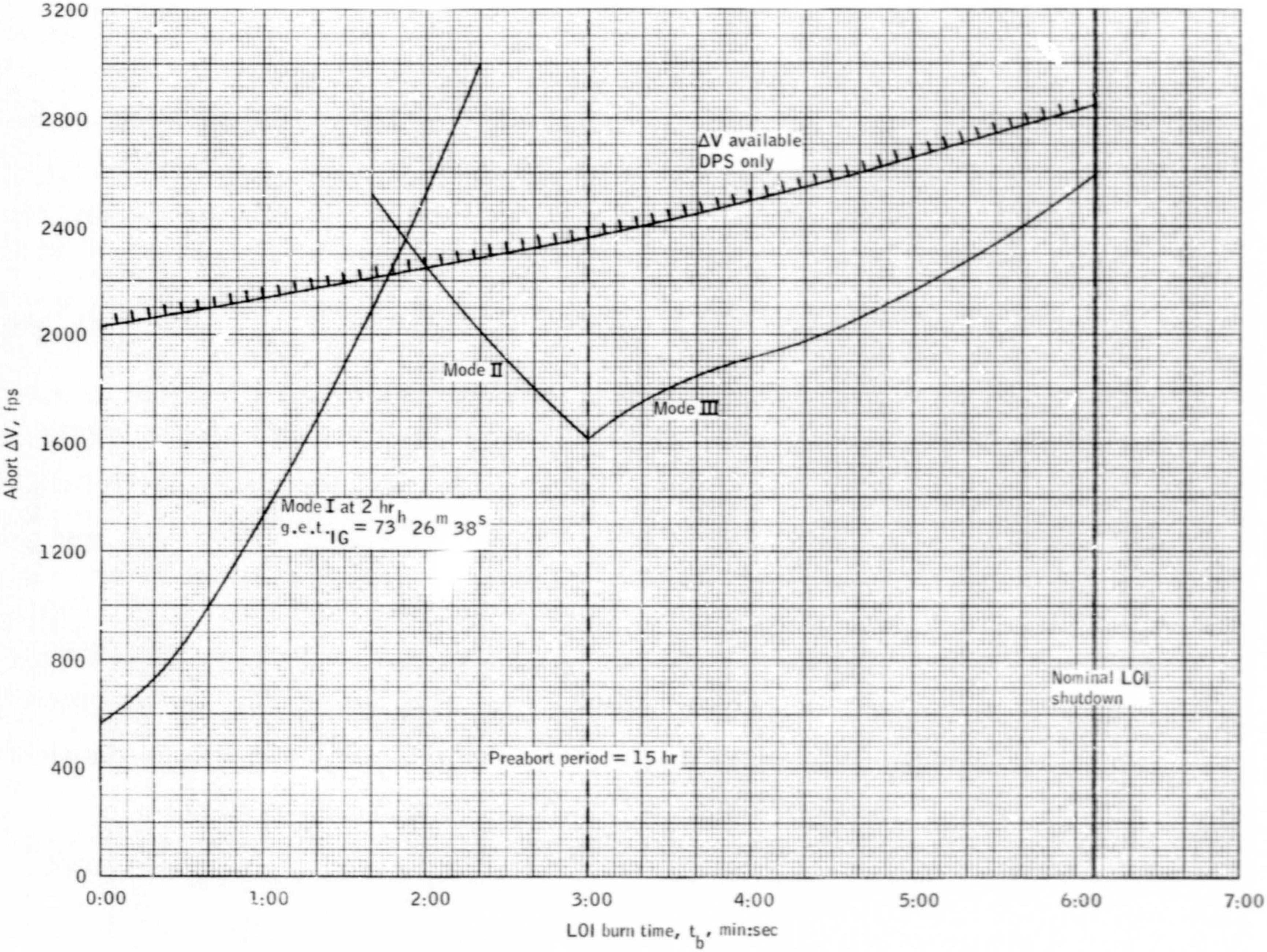
(d) August 16, 1969; 72° launch azimuth; first opportunity.

Figure 4.- Continued.



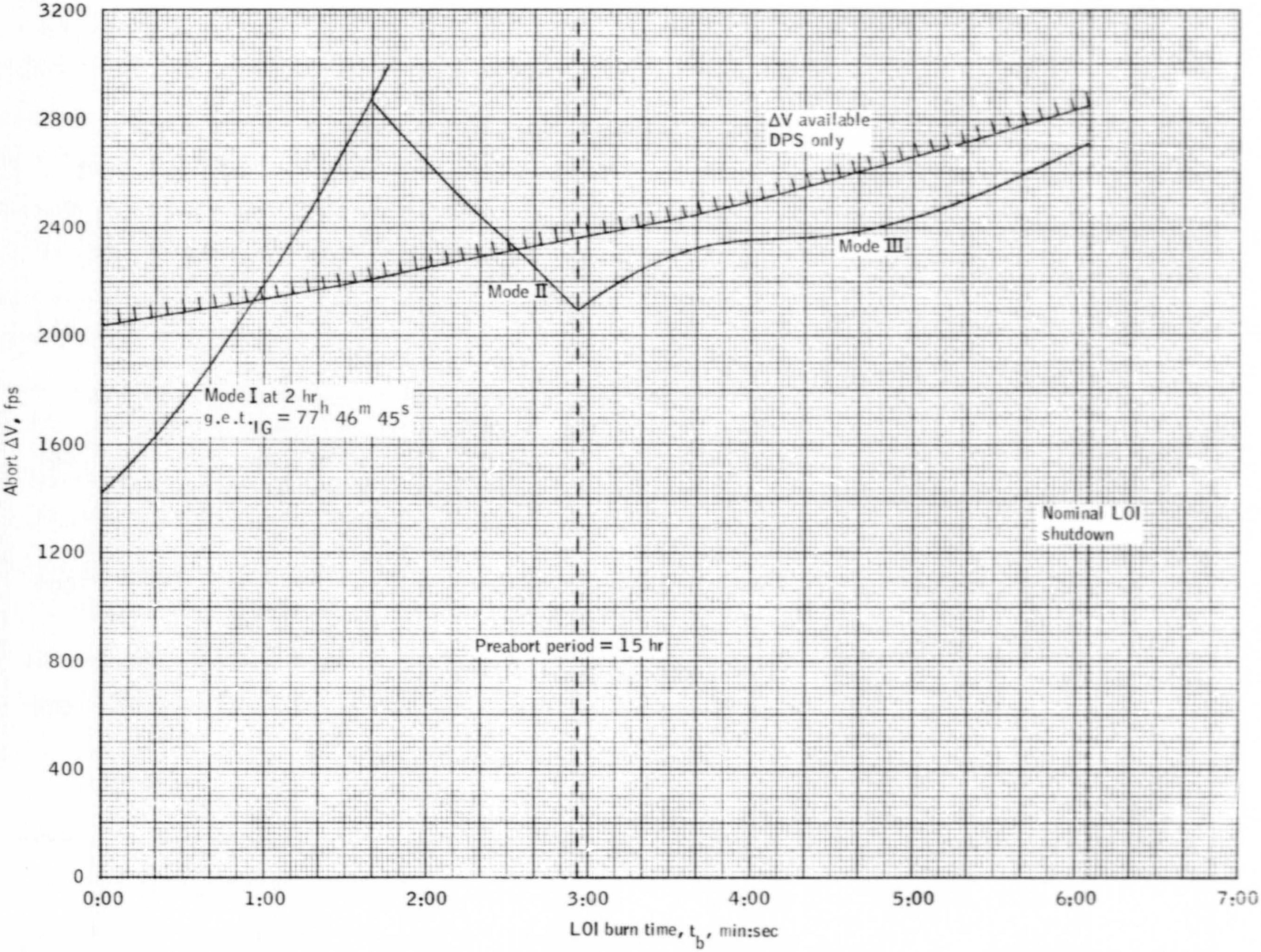
(e) August 20, 1969; 72° launch azimuth; first opportunity.

Figure 4.- Continued.



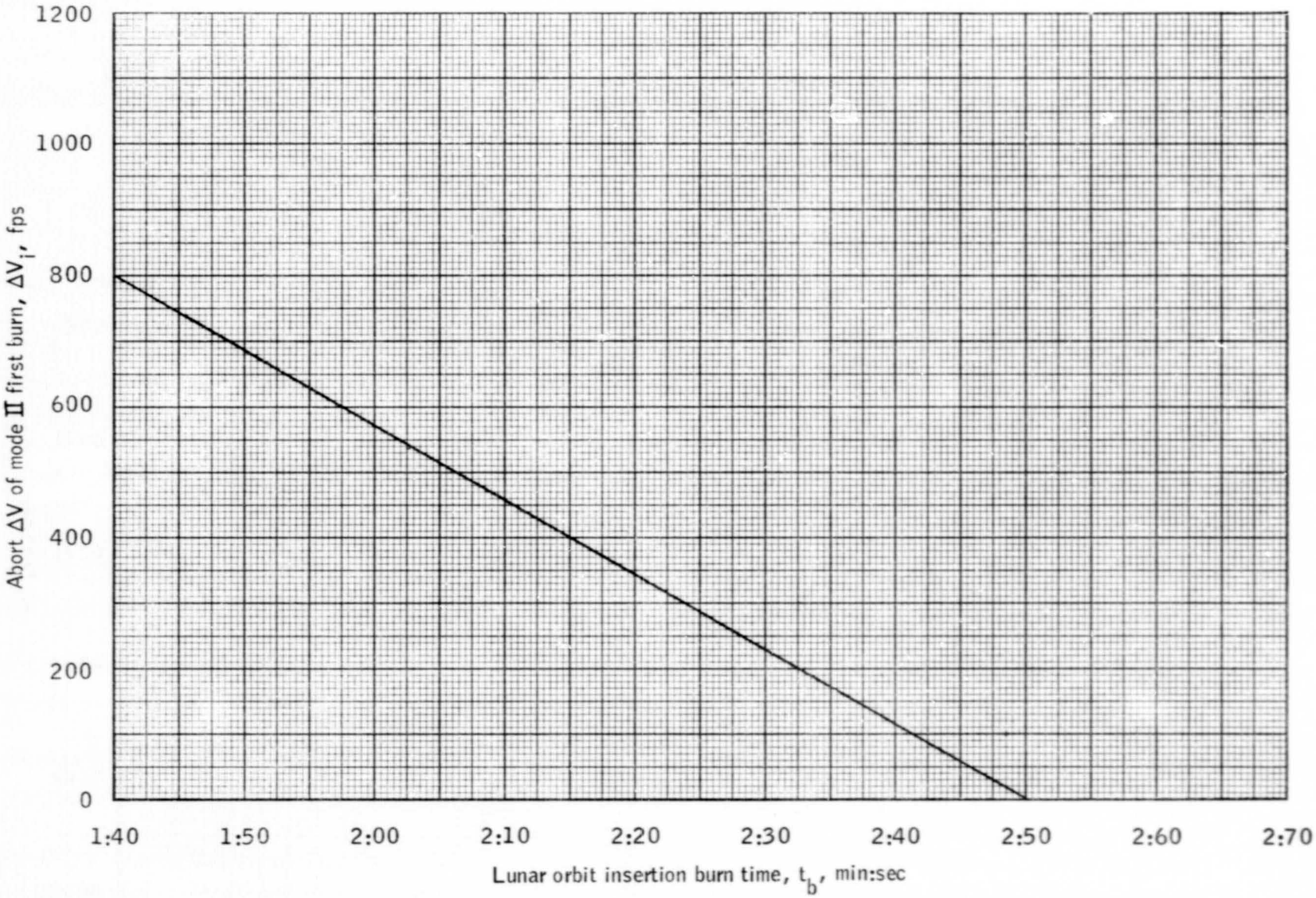
(f) September 15, 1969; 72° launch azimuth; first opportunity.

Figure 4.-Continued.



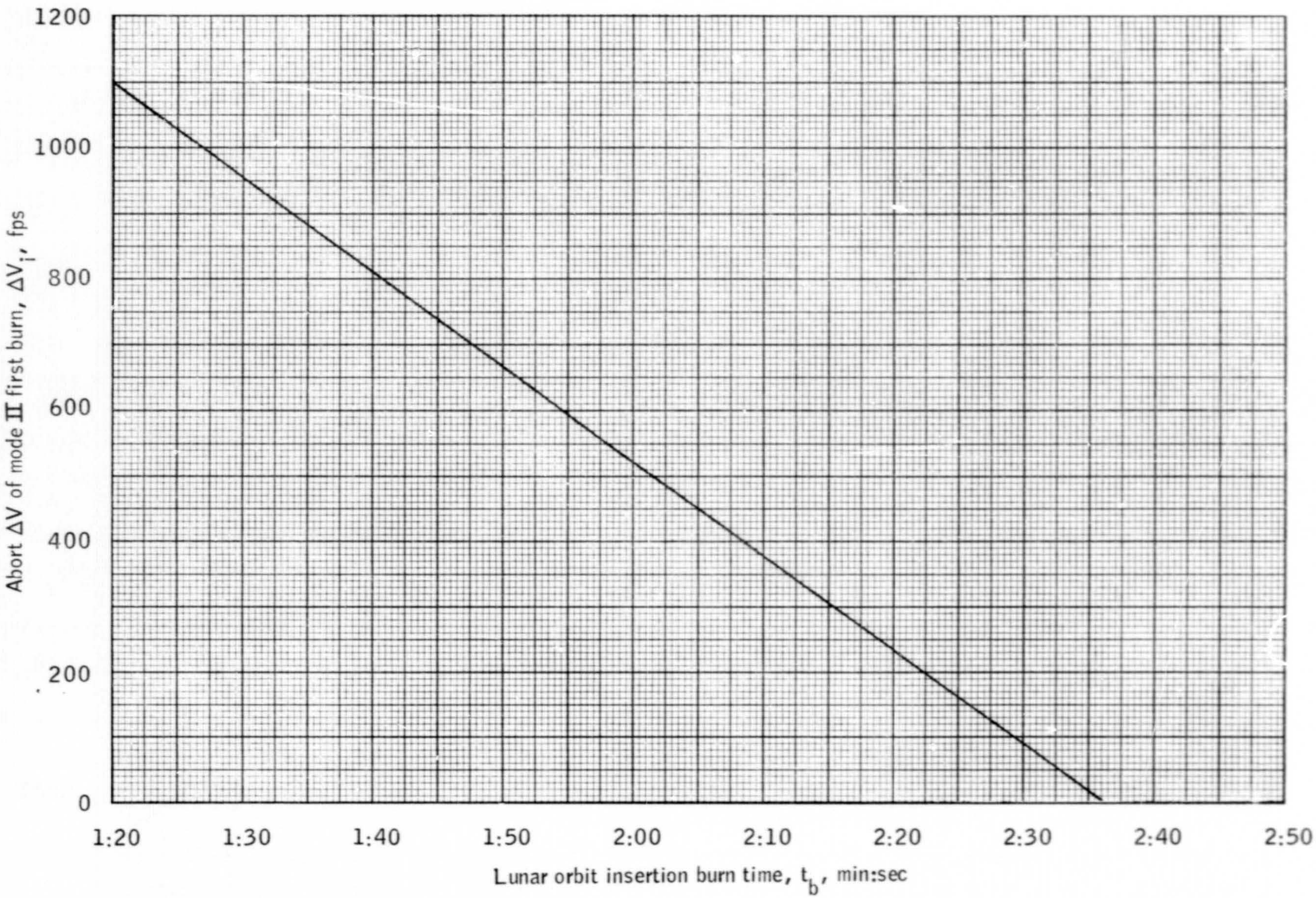
(g) September 18, 1969; 72° launch azimuth; first opportunity.

Figure 4.- Concluded.



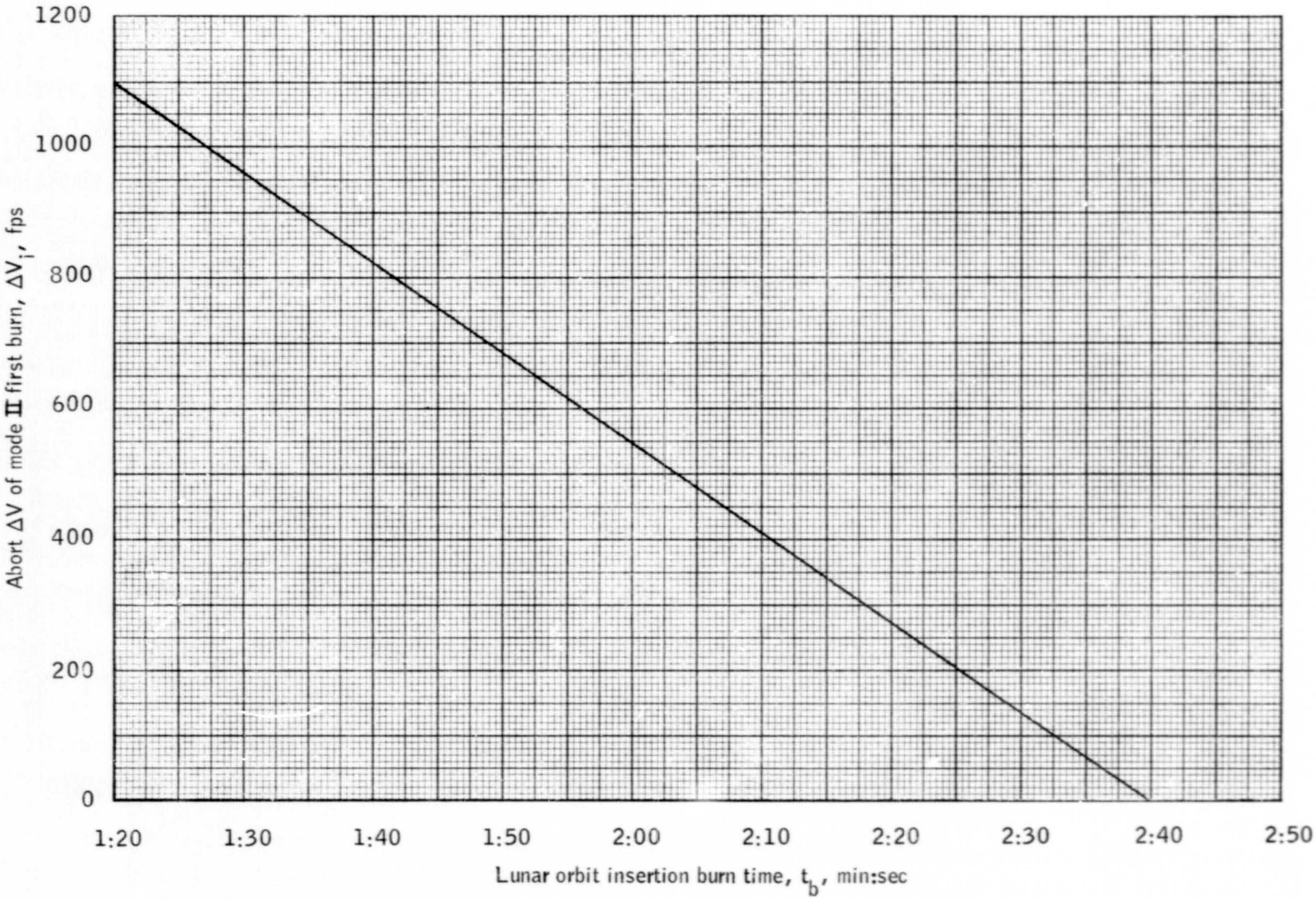
(a) Launch date of July 18, 1969.

Figure 5. - ΔV magnitude of first mode II burn for various hybrid lunar missions.



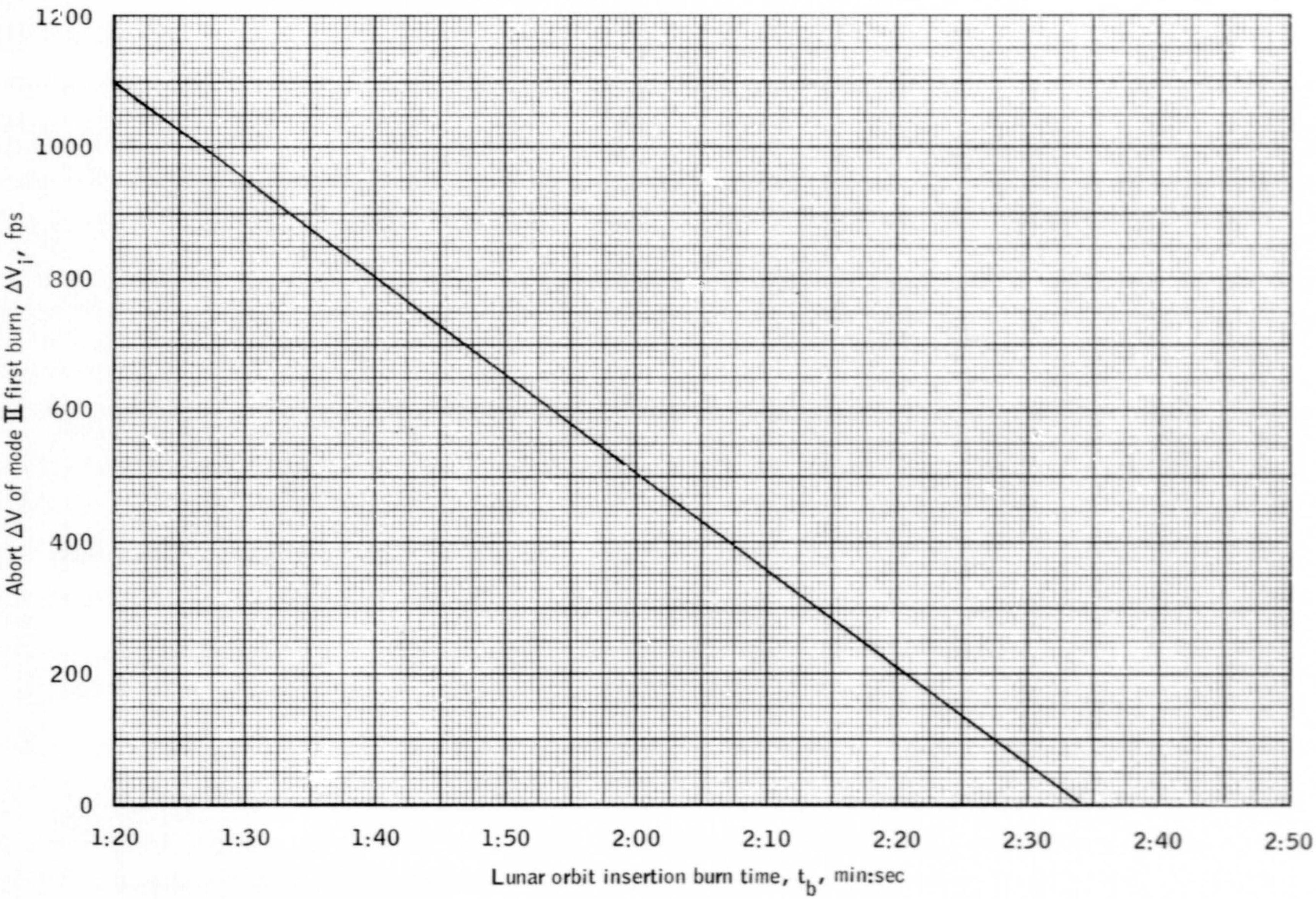
(b) Launch date of July 21, 1969.

Figure 5.- Continued.



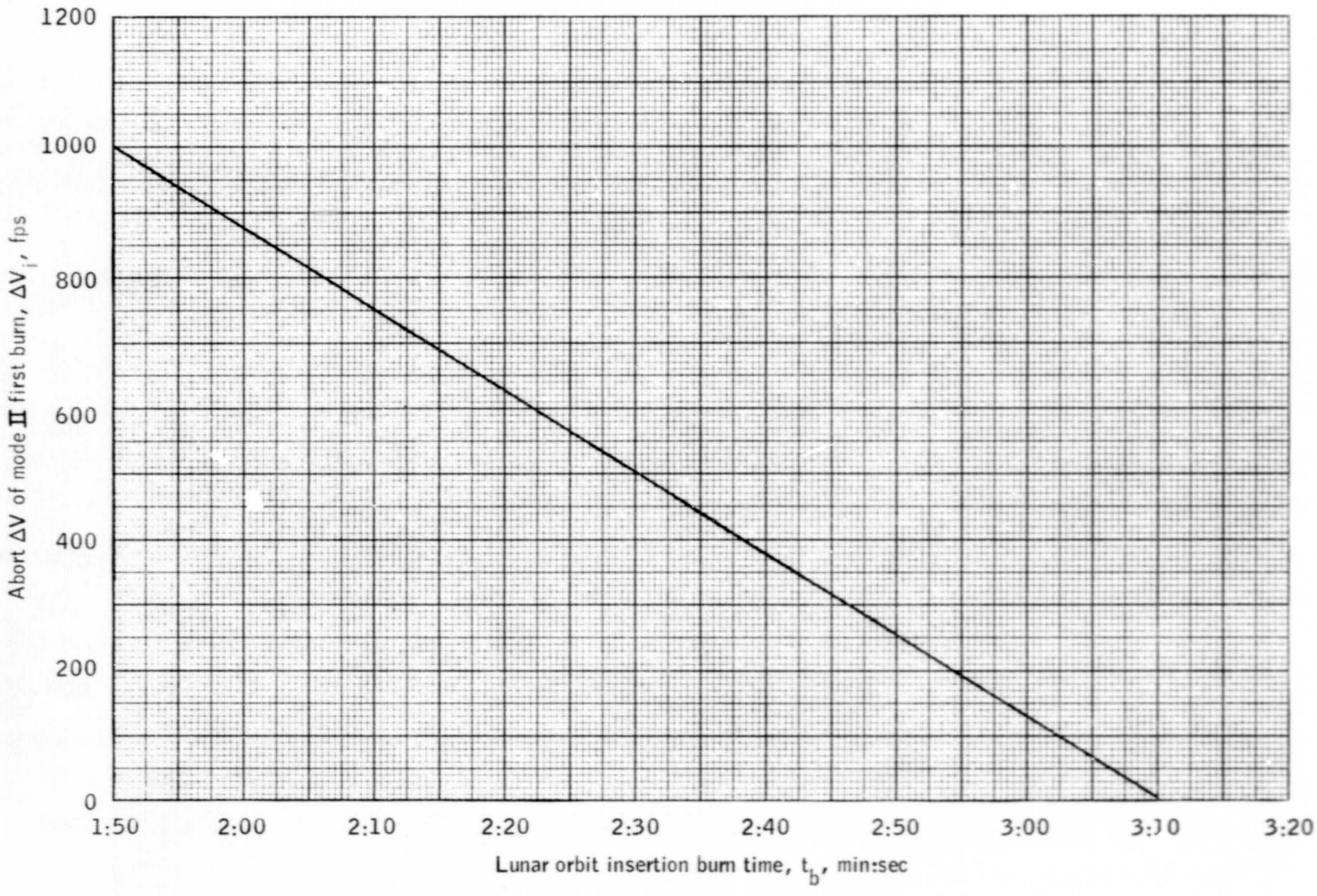
(c) Launch date of August 14, 1969.

Figure 5.- Continued.



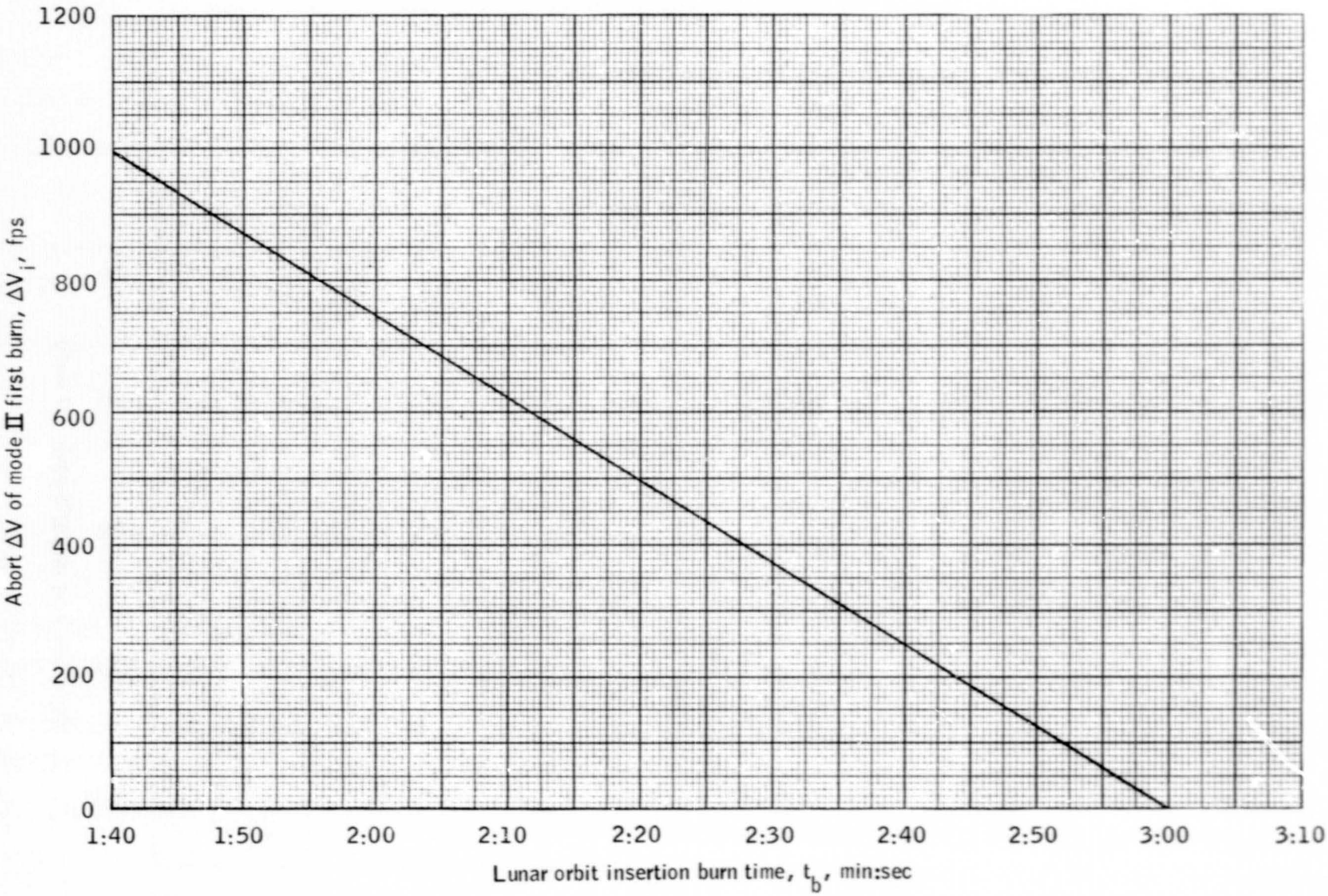
(d) Launch date of August 16, 1969.

Figure 5.- Continued.



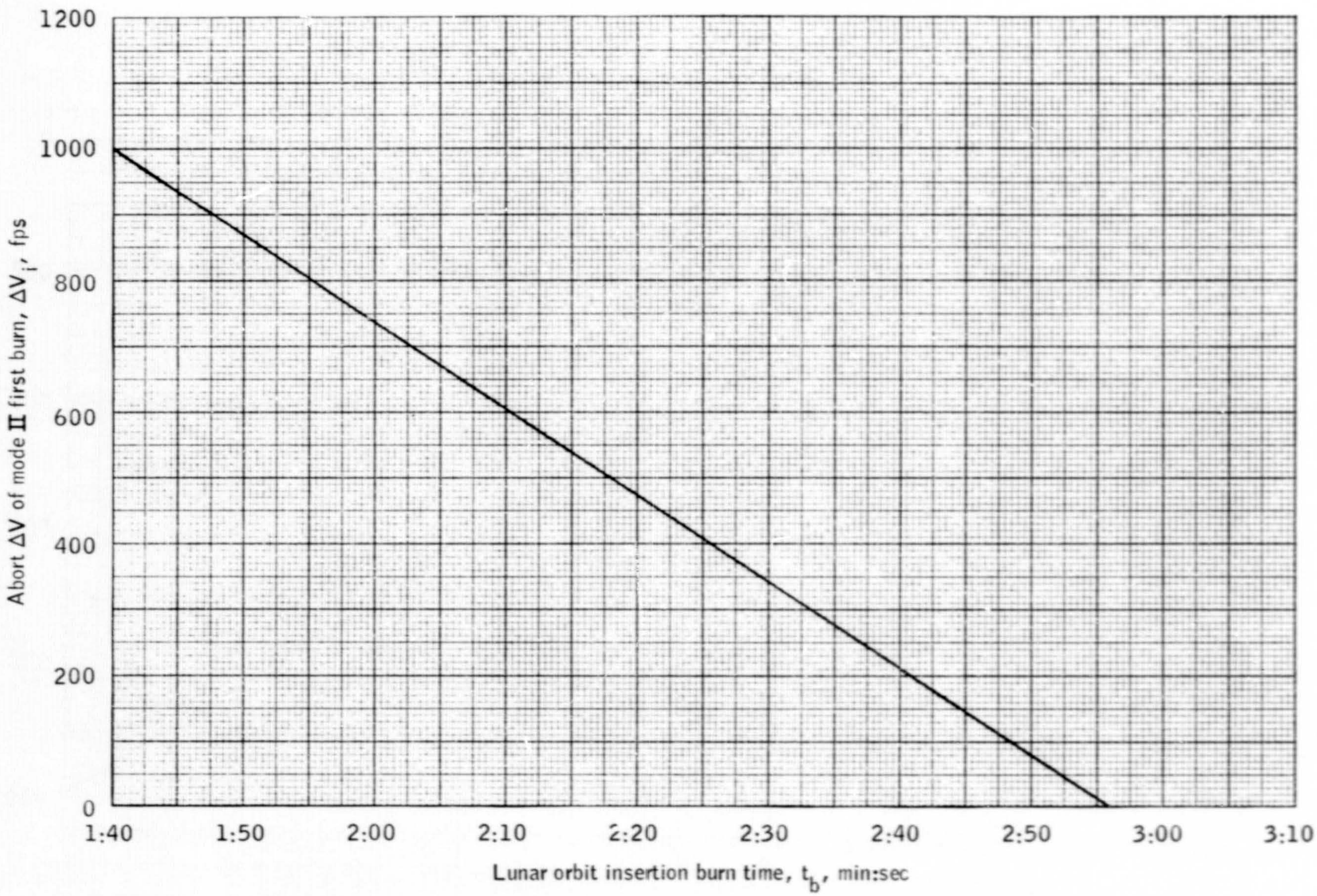
(e) Launch date of August 20, 1969.

Figure 5.- Continued.



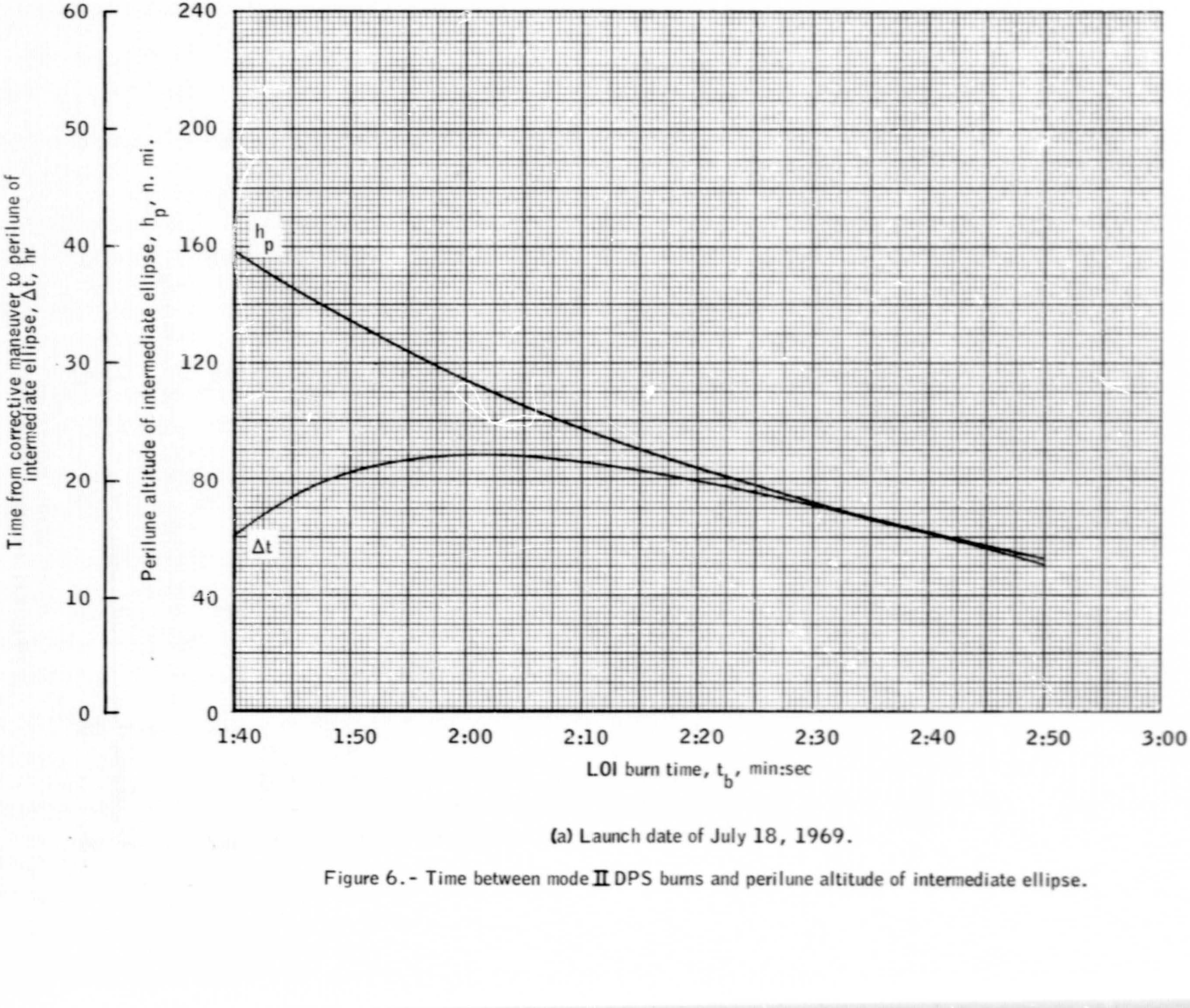
(f) Launch date of September 15, 1969.

Figure 5.- Continued.



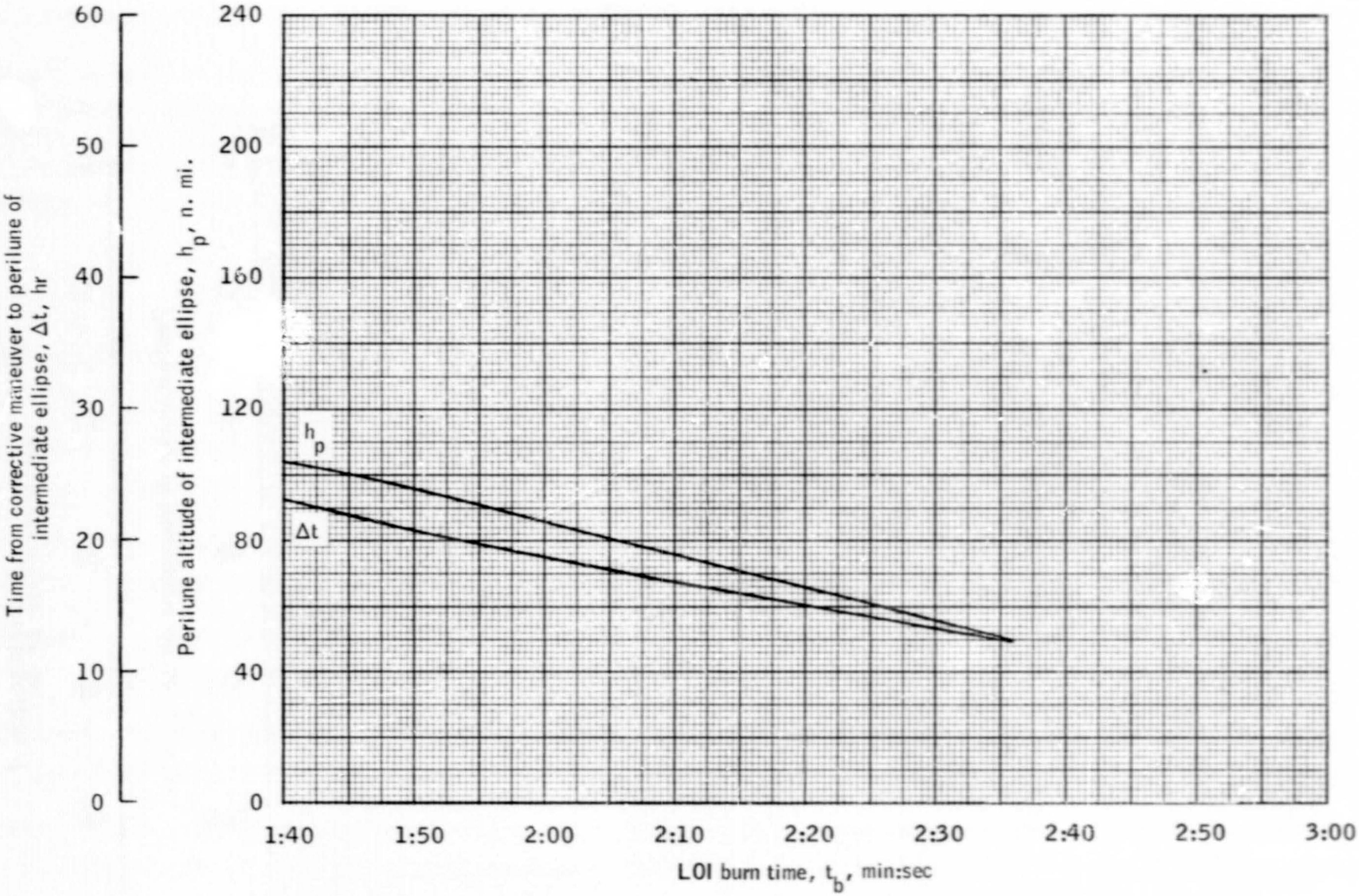
(g) Launch date of September 18, 1969.

Figure 5.- Concluded.



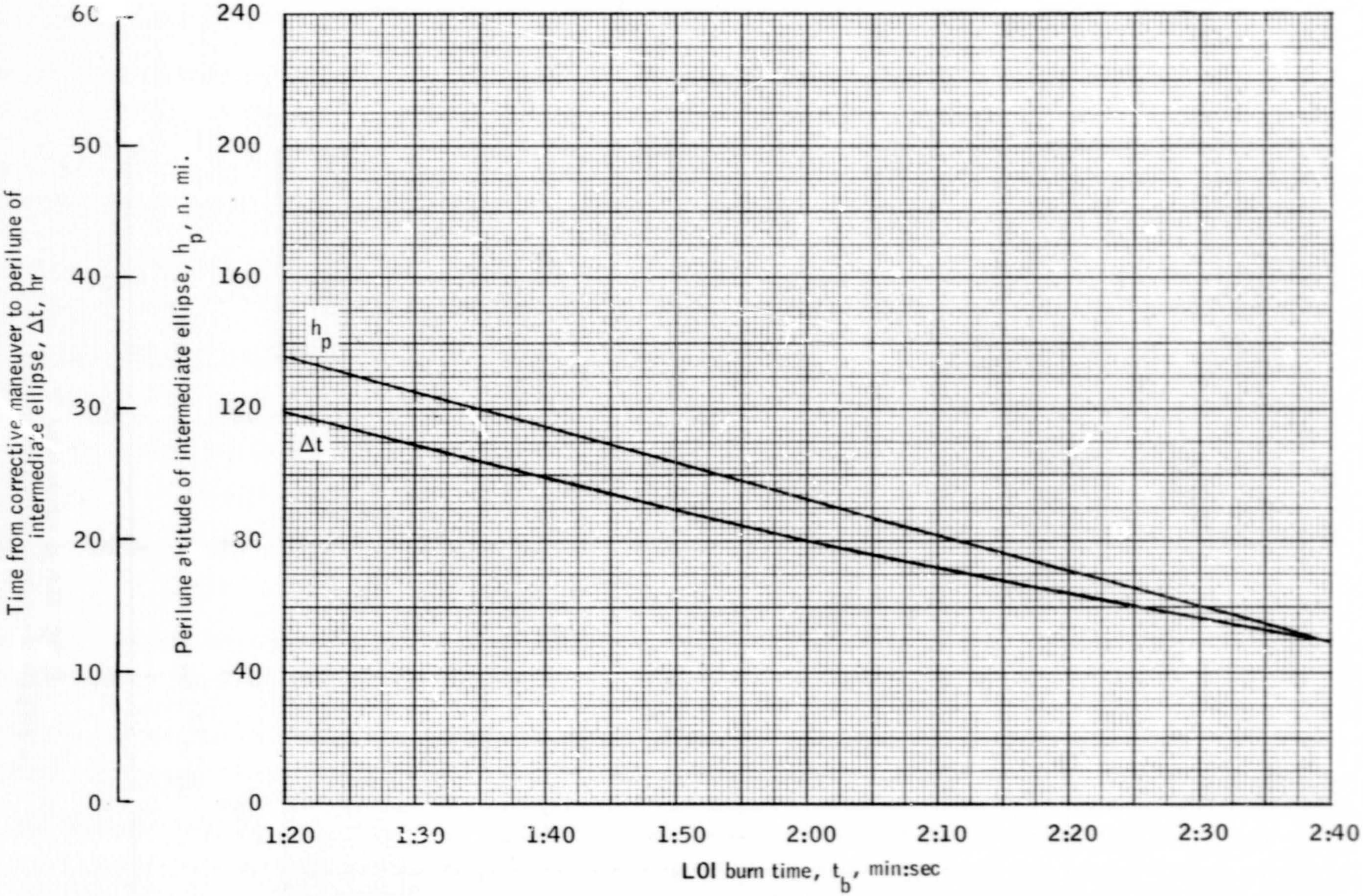
(a) Launch date of July 18, 1969.

Figure 6.- Time between mode II DPS burns and perilune altitude of intermediate ellipse.



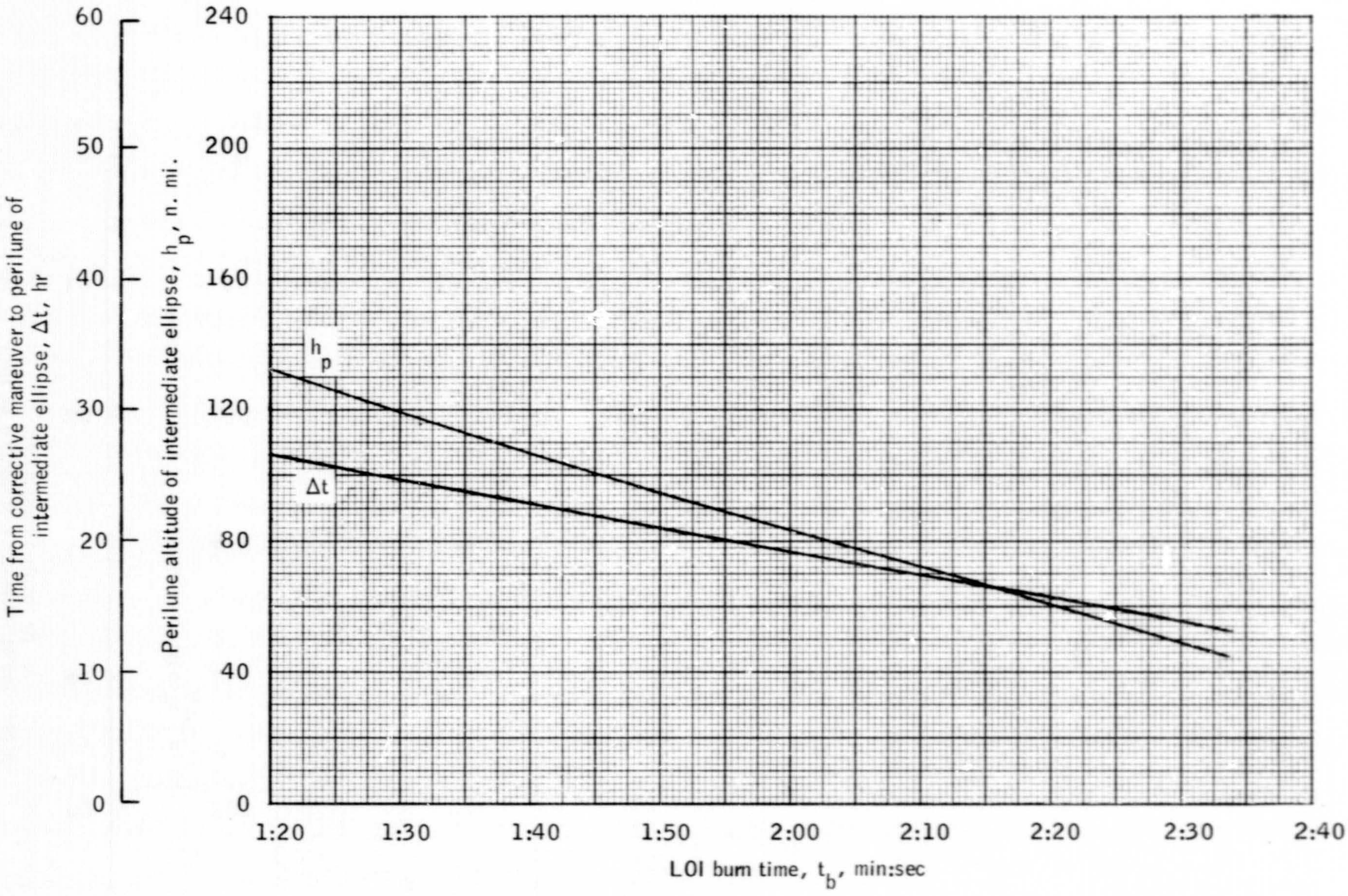
(b) Launch date of July 21, 1969.

Figure 6.- Continued.



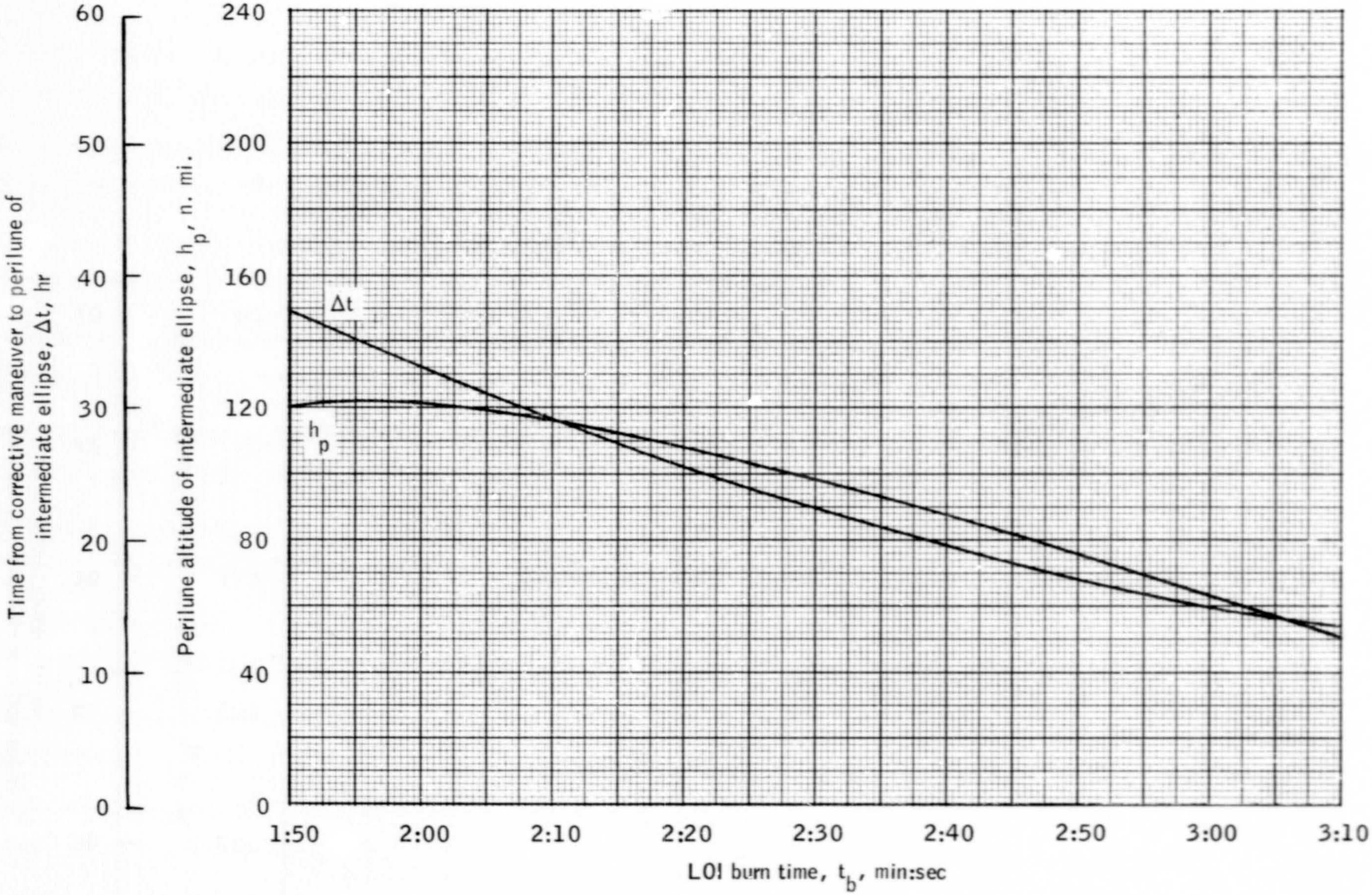
(c) Launch date of August 14, 1969.

Figure 6.- Continued.



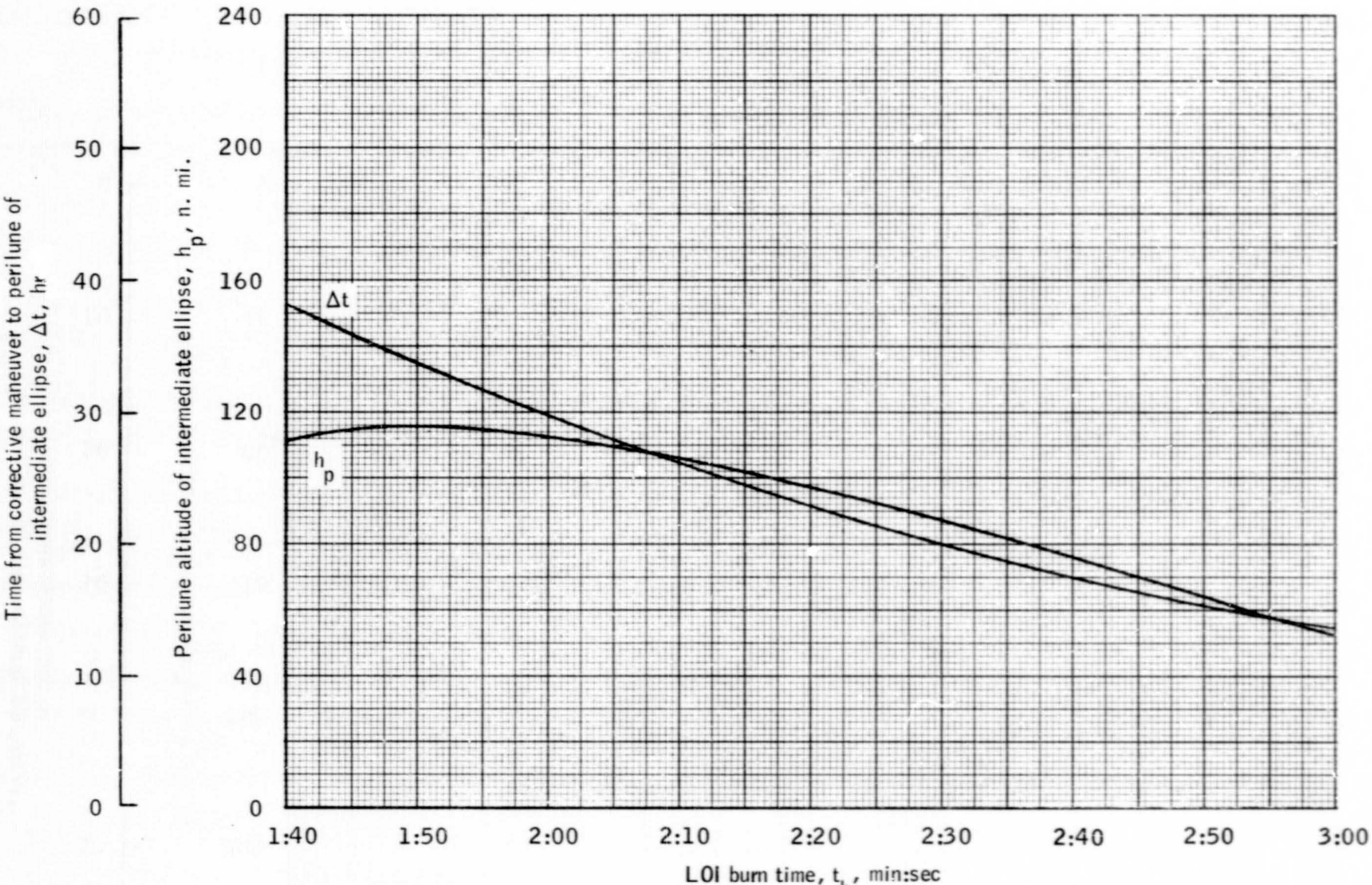
(d) Launch date of August 16, 1969.

Figure 6.- Continued.



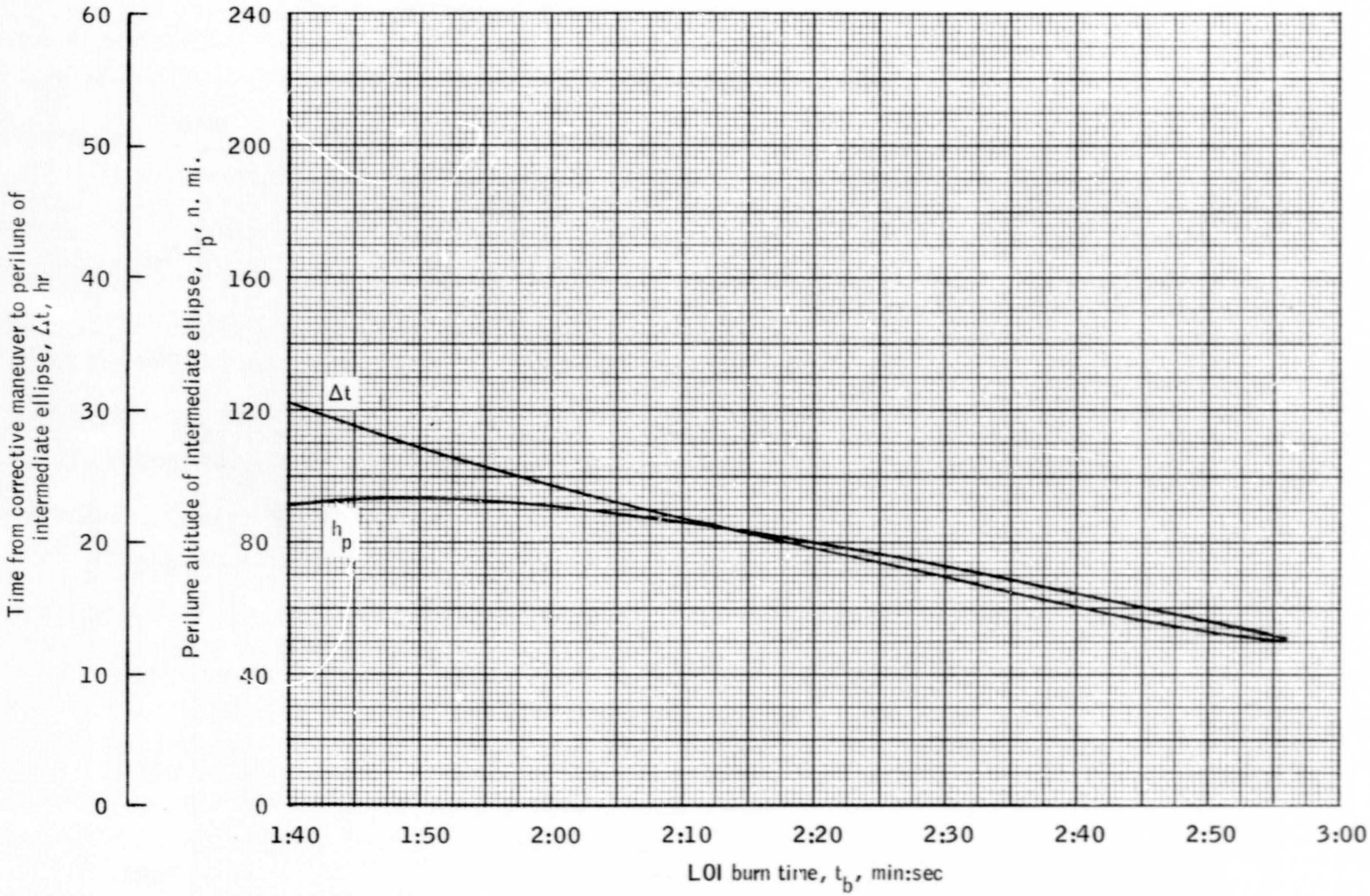
(e) Launch date of August 20, 1969.

Figure 6.- Continued.



(f) Launch date of September 15, 1969.

Figure 6.- Continued.



(g) Launch date of September 18, 1969.

Figure 6.- Concluded.

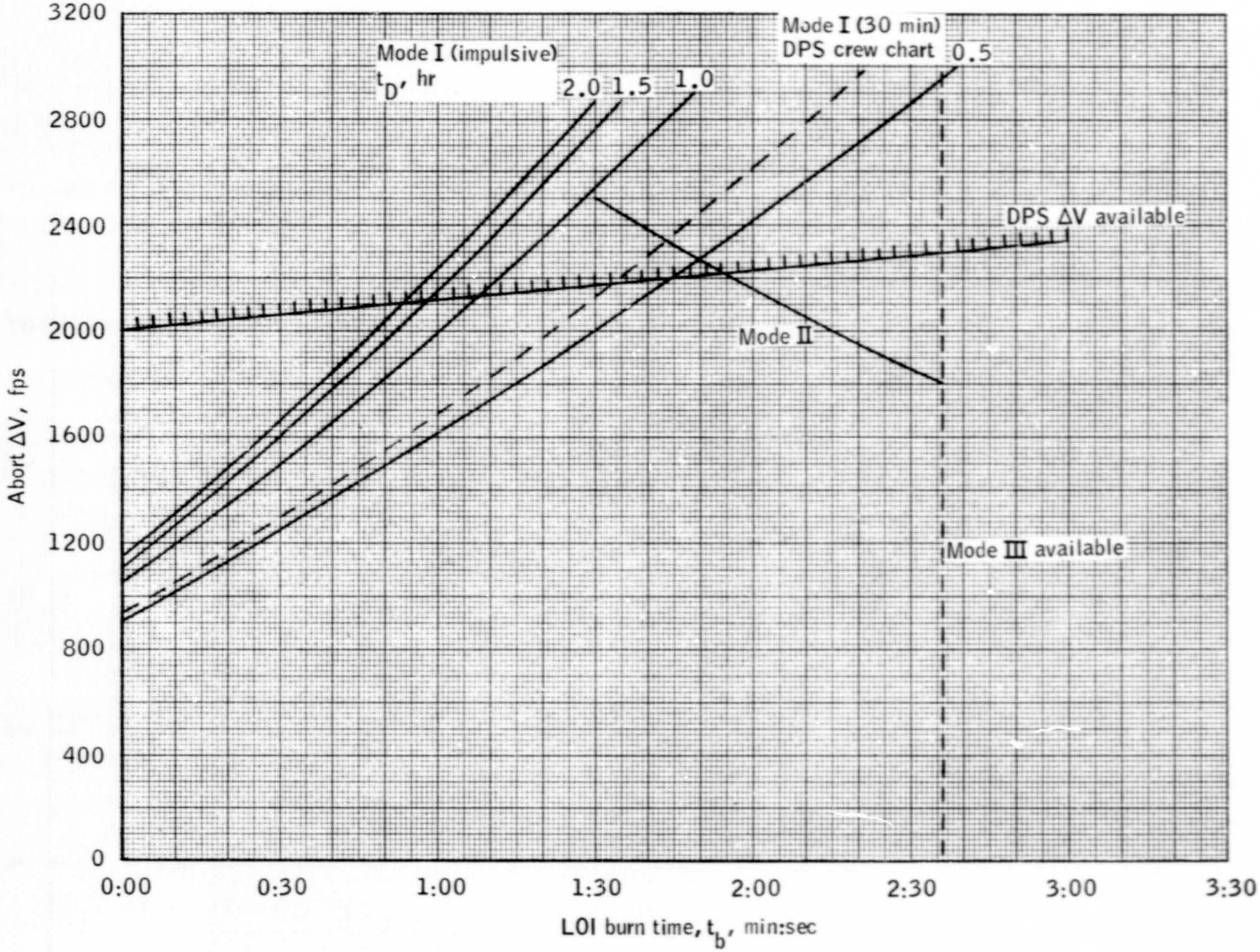
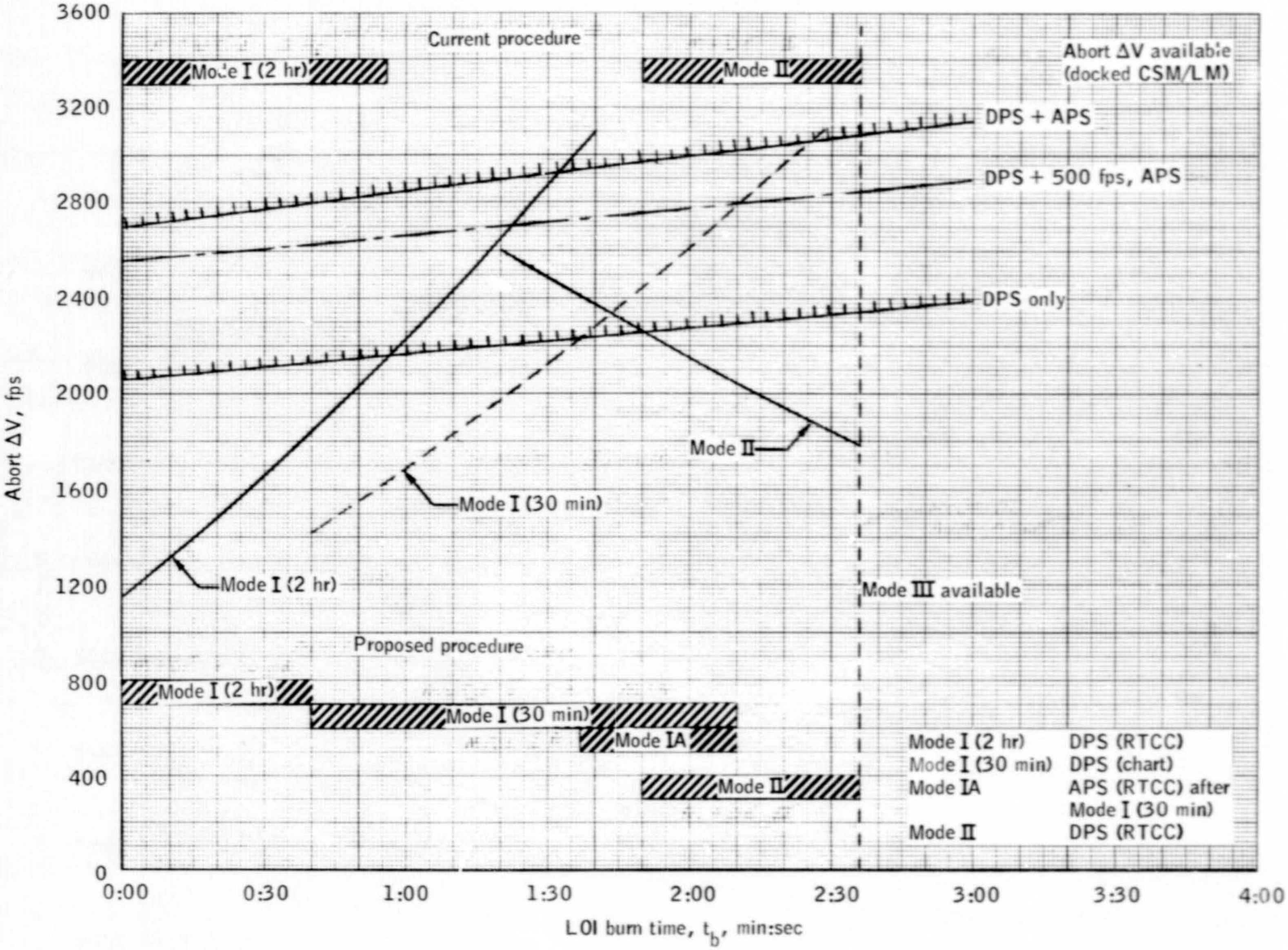
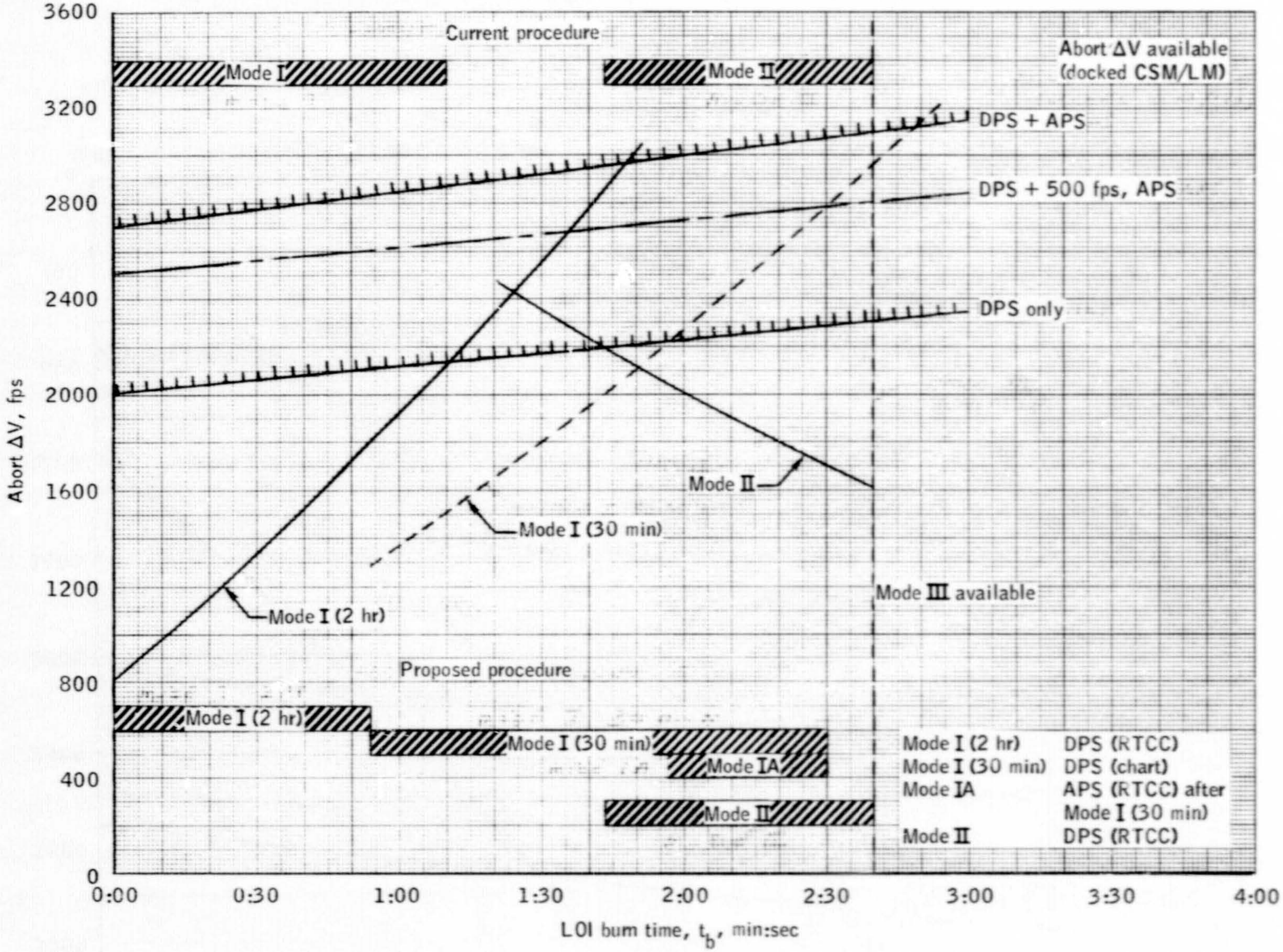


Figure 7.- Comparison of mode I DPS capability for various times of ignition (July 21, 1969).



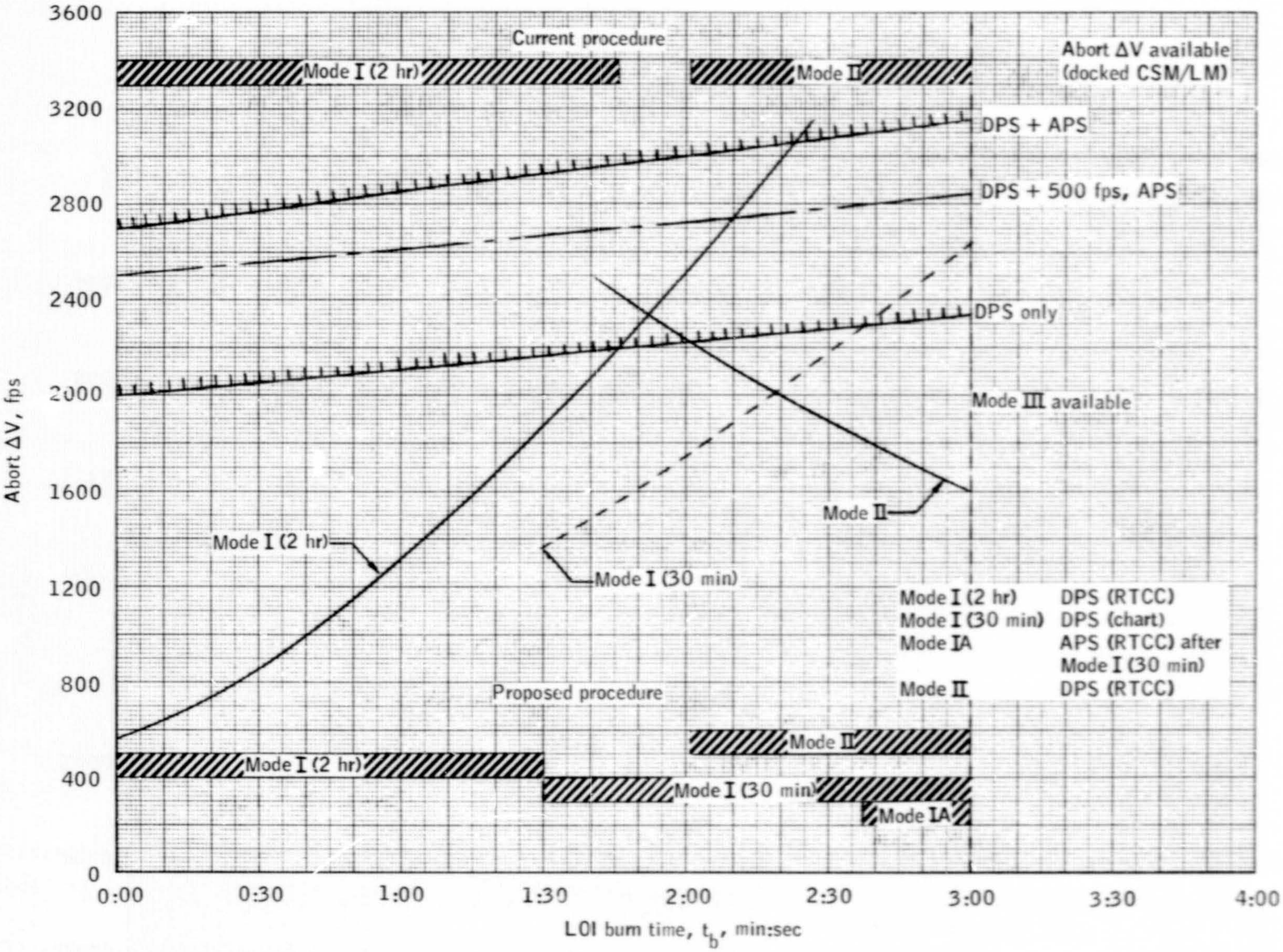
(a) July 21, 1969.

Figure 8.- Comparison of abort capability resulting from current and proposed LOI abort procedures (FCUA returns).



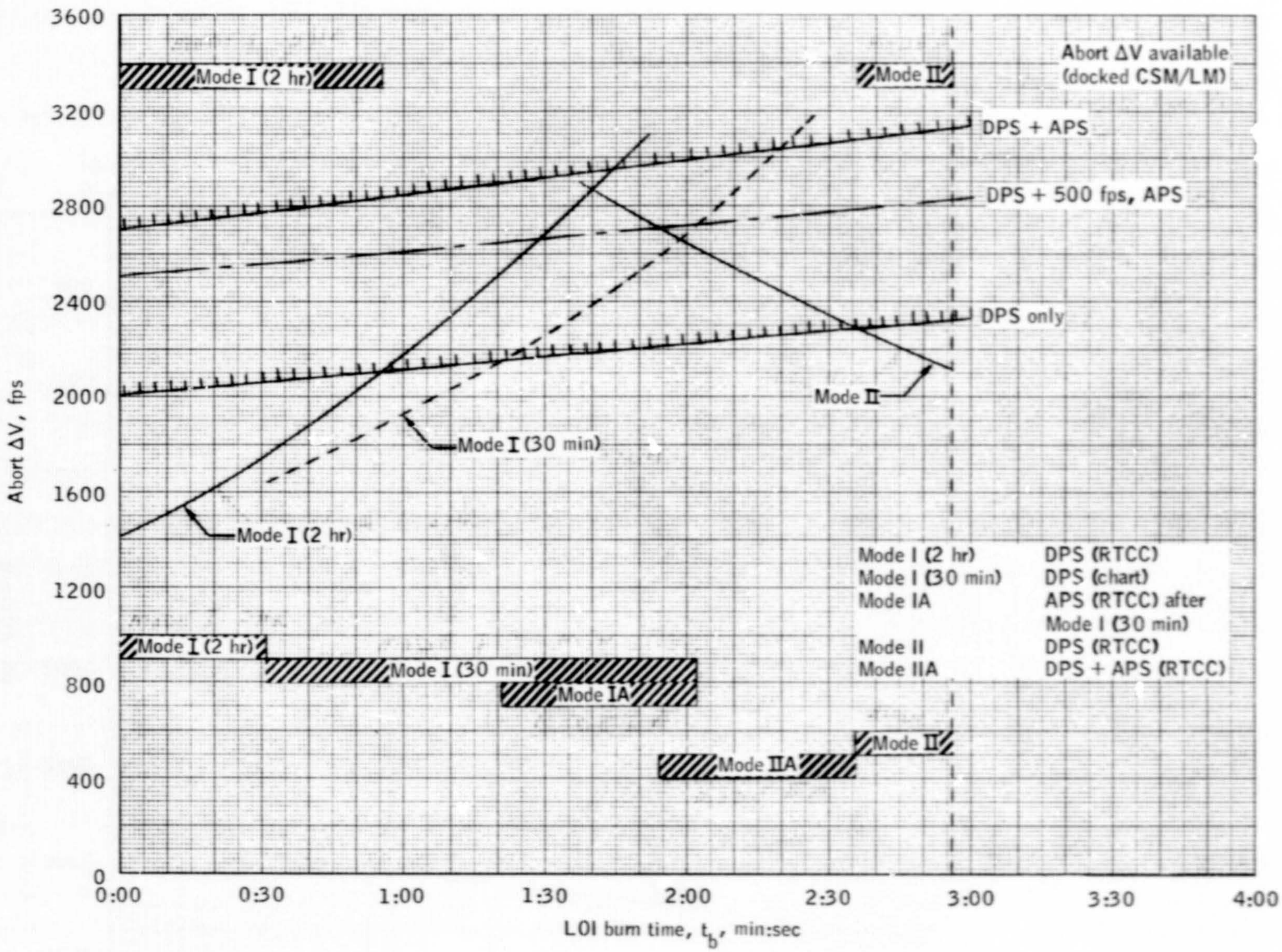
(b) August 14, 1969.

Figure 8.- Continued.



(c) September 15, 1969.

Figure 8.- Continued.



(d) September 18, 1969.

Figure 8.- Concluded.

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